PETROLOGY OF THE VOLCANIC ROCKS OF THE WHALESBACK AREA, SPRINGDALE PENINSULA, NEWFOUNDLAND

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Petrology of the Volcanic Rocks of the Whalesback Area, Springdale Peninsula, Newfoundland

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ABSTRACT

Detailed mapping in the vicinity of the Whalesback Mine has established the feasibility of consistently distinguishing two types of metabasalts in a poorly exposed and rather montonous sequence of mainly pillowed volcanics, part of the Lower Ordovician Lush's Bight Group. The two types, called the 'Whalesback' and 'St. Patrick' volcanics, each have a mineral assemblage characteristic of the greenschist facies - albite, epidote, chlorite, actinolite and leucoxene - but are distinguished in the field by their relative abundances of epidote and chlorite, respectively. Intercalated with the flows are discontinuous lenses of pyroclastic rocks. Gabbroic equivalents of the flows are present in dykes, sills and small stocks. The whole sequence is cut by a set of feldspar, amphibole-feldspar, and pyroxene porphyry dykes.

The poor exposure and the general paucity of primary stratification features make structural analysis very difficult. There is, however, some petrologic indication that the St. Patrick volcanics are stratigraphically above the Whalesback volcanics and the general outcrop pattern suggests an overall anticlinal structure. The area is cut by two major, northeasterly-trending faults, the Davis Pond and Little Deer Pond faults. Minor faulting and shearing has affected all parts of the area but is particularly prevalent in the north block which is also characterized by a relative abundance of porphyritic dykes.

The Whalesback and Little Deer sulfide orebodies are contained in adjacent, east-west trending shear zones, to the north of and subsidiary to the Little Deer Pond fault. The host rocks are chlorite and chlorite-sericite schists which were derived, at least in part, from pyroclastic rocks.

A detailed petrographic and chemical study was carried out, concentrating mainly on the flow rocks. Seventeen complete and ten partial chemical analyses were obtained. These show that the Whalesback and St. Patrick volcanics are tholeiitic basalts and basaltic andesites, respectively, that have been affected by metasomatism, mainly addition of soda. The two flow types appear to form part of a differentiation series that is characterized by consistently low potash suggesting a correlation with oceanic tholeiites.

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The study was carried out with the full co-operation of British Newfoundland Exploration Limited (Brinex) who employed the writer during the period when the field work was done and provided those chemical analyses done at the University of Pittsburgh. Thanks are especially due to Dr. A.P. Beavan and Mr. H.R. Peters for their assistance and continuing interest.

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CHAPTER I

INTRODUCTION

Location of the Area

This study is concerned primarily with the petrology of the basic volcanic and associated rocks in the vicinity of the Whalesback mine. The mine is situated on the Springdale Peninsula, in the southwestern corner of Notre Dame Bay (see Figs. 1 & 2). It is reached from the Trans-Canada Highway (Route 1) via Route 57, the Springdale road, and Route 43, the road to Little Bay. The Whalesback access road joins Route 43 approximately 3/4 miles south of the village of St. Patrick's. The town of Springdale, located on Hall's Bay some 7 miles south of the mine, is the commercial center of the region.

The Whalesback area is approximately 4 miles long by 2 miles wide, roughly centered around co-ordinates $46^{\circ}36'$N and $56^{\circ}00'$W (see Fig. 1). The Whalesback mine is located in the north-central part of the area. Also within the area, west of the Whalesback mine, is the Little Deer mine, which is under development. The Whalesback road traverses the western portion of the area and the Little Bay road skirts the southern boundary. From these roads, the area is accessible on foot via the Whalesback cut grid, the power lines to the Whalesback and Little Bay mines, and a number of tractor roads and trails.

Physiography

The regional physiographic features of Western Notre Dame Bay have been described by Twenhofel and MacClintock (1940) and Maclean (1947). The Whalesback area, like most other parts of the region, displays a prominent northeasterly topographic 'grain' reflecting the dominant structural trend. Relief within the area is less than 300 feet. The highest elevations are just over 650 feet on the ridge north of Little Deer Pond. In the southwestern corner of the area the elevations approach sea level in the valley trending to Little Bay.

The largest bodies of water are Whalesback and Little Deer Ponds. The remainder of the area is dotted by many small ponds and numerous marshy areas. Drainage via small brooks is generally toward the northeast. Plates I and II illustrate the topography of the area.

An ubiquitous, though usually thin, cover of coarse till supports a dense tree growth and obscures much of the bedrock. The best exposures are usually found on ridge and hill tops but all exposures have been rounded by glacial action and some are striated. Erratics, generally coarse grained granitic rocks, are common.

Whalesback Pond has now been partially drained to provide sites for mine buildings, thus greatly improving bedrock exposure in the vicinity of the Whalesback ore zone (see Plates III & IV).

Previous Work

Geological studies in Western Notre Dame Bay were begun in 1864 by Alexander Murray and were continued intermittently by him and later by his assistant and successor, J.P. Howley, until 1909 (Murray and Howley, 1881, 1918). This work delineated, very generally, the area of western Notre Dame Bay which is underlain by basic volcanic and related rocks. Howley's geological map of Newfoundland, first published about 1905, summarized the knowledge of the region up to that time; it showed all of Western Notre Dame Bay as being underlain by one unit described as "Serpentines, diorites, dolerites, etc." Many of the mineral deposits had, however, been studied in relative detail and there are few occurrences known today which were not located on Howley's map.

Mining had started in the region before the commencement of Murray's work and continued a healthy development until about 1900 before declining. An account of the industry at the peak of its development was given by Wadsworth (1884) who visited many of the mines including the one at Little Bay and noted the rock types occurring in the vicinity.

Little was published on the region between Howley's retirement in 1909 and the late 1930's. Sampson (1923) studied the cherts associated with the volcanic rocks and suggested that they were formed as colloidal precipitates in a marine environment enriched in silica by the volcanic activity. Snelgrove (1928) published a collation of the geology of central Newfoundland in which he applied the term 'Central Mineral Belt' to the western part of Notre Dame Bay and the southward extension of the volcanic rocks. Snelgrove's map was based largely on that of Howley which still formed the best available regional synthesis.

In the 1930's the Geological Survey of Newfoundland began a program of regional studies which greatly elucidated the geology of the Notre Dame Bay region. The first of these was a study of the Pilley's Island area, to the east of the Springdale Peninsula, by Espenshade (1937) who applied the term 'Lush's Bight Group' to a volcanic assemblage there. Maclean (1947) mapped the adjacent Little Bay area, including the Whalesback area, and correlated the rocks there with Espenshade's Lush's Bight Group. A study of the copper deposits of the region was published in 1940 (Douglas et al., 1940).

A program of regional mapping begun in the 1950's by the Geological Survey of Canada resulted in the publication by Neale and Nash (1963) and Williams (1962) of maps each of which includes part of the Whalesback area. Other Geological Survey of Canada publications dealing with rocks related to the Lush's Bight Group in adjacent areas are those of Baird (1951), Neale (1958 a & b, 1959), and Neale, Nash and Innes (1960).

More recent studies have been aimed at elucidating the stratigraphic and tectonic development of the Central Mobile Belt and particularly the role of ocean floor spreading and closing in its development. Published accounts of these studies having the most bearing on the area under consideration here are those of Williams (1964), Neale and Kennedy (1967), Kay (1967 & 1969), Dewey (1969), and Bird and Dewey (1970).

The Western Arm section of the Lush's Bight Group has recently been studied by Marten (in preparation). Sayeed (1970) has studied the association between the Lush's Bight lavas and the Colchester and Cooper's Cove plutons on the western side of the Springdale Peninsula.

The mining industry of Western Notre Dame Bay was revitalized in the late fifties and early sixties, first by the reopening of the Tilt Cove and Little Bay mines and later by the development of the Whalesback and Little Deer properties. Detailed mapping, centered around Whalesback and Little Deer Ponds has been carried out by British Newfoundland Exploration Limited (Brinex) under the direction of H.R. Peters. Kanehira and Bachinski (1968) published the results of a study on the mineralogy and textural relationships of the Whalesback ore. An investigation of the distribution of thermoluminescence around the Whalesback ore body was carried out by McDougall (1966).

Preliminary results of the present study have been reported by Papezik and Fleming (1967).

Present Work - Aims and Methods

Newfoundland's Central Mineral Belt, in which the Whalesback area is located, has been a relatively important base metals - chiefly copper - producing region for approximately 100 years. Mainly because of its economic importance the belt has been the object of much geological study, but this has included only a very limited amount of petrological work despite the close association between the mineral deposits and basic volcanic rocks (Williams, 1963).

In recent years Newfoundland, and particularly the central belt, has become one of the key areas in the study of continental drift. Because of this the Notre Dame Bay area, in particular, has come under the scrutiny of many geologists. Most of the work, however, has been of a regional-stratigraphic nature; little has been done to elucidate the petrologic character and development of the extensive volcanic rock assemblages. In particular, the Lush's Bight Group, the predominantly volcanic assemblage which hosts the Whalesback and Little Deer deposits as well as those of the Little Bay Mine and numerous other mineral occurrences, has been very inadequately understood.

The exploration and development of the Whalesback and Little Deer copper deposits by British Newfoundland Exploration Limited (Brinex) afforded the opportunity for the initiation of petrological studies in conjunction with the detailed mapping being carried out in the area. This study was undertaken with the primary aim of contributing to a better understanding of the geological environment of the Whalesback and Little Deer deposits through detailed mapping and petrological studies. The petrological data gathered here may also contribute toward an understanding of the development of the central mobile belt.

This study was initiated in 1965 when the writer (Fleming, 1965) mapped in detail the area around Little Deer Pond and the western end of Whalesback Pond. Control was provided by the Whalesback grid of cut lines and the results were plotted at 400 feet to 1 inch. Other parts of the Whalesback area were similarly mapped by Drover (1963), Gandhi (1964), and Papezik (1965). All the maps were compiled by the writer on a scale of 800 feet to 1 inch; the results are shown in Figure 1.

A petrographical and chemical study was carried out on specimens collected from the areas mapped by Papezik, Gandhi and the writer. This involved thin section studies, including universal stage determinations, X-ray diffraction studies of chlorite concentrates, and complete and partial chemical analyses. The work was concentrated on elucidating the character and origin of the rather monotonous sequence of lavas. These are the most abundant rocks of the area and some insight into their nature must be gained as the logical first step in unraveling the geology of the area as a whole. Relatively less attention was paid to the other, less abundant, rock types of the area which include pyroclastics and gabbroic rocks associated with the lavas, and some younger dyke rocks.

CHAPTER 2

REGIONAL GEOLOGICAL SETTING

Introduction

The Island of Newfoundland, the most northeasterly extension of the Appalachian mountain belt, is composed of three major tectonic elements (see Fig. 2); a central Paleozoic mobile belt of eugeosynclinal facies is bounded on the northwest and southeast by Precambrian platform rocks overlapped by Lower Paleozoic shelf facies strata (Williams, 1964). The central belt displays a symmetry which was described by Williams (1964, p. 1139):

> "... (a) its margins are marked on both sides by extensive sedimentary clastic deposits or their metamorphosed equivalents; (b) these clastic deposits are bounded toward the center of the basin by thin zones of ultramafic intrusions; (c) these ultramafic zones are followed inward by extensive thicknesses of Ordovician and Silurian volcanic and sedimentary rocks."

The Whalesback area is located within the west-central portion of the mobile belt some twenty miles east of the western ultramafic zone.

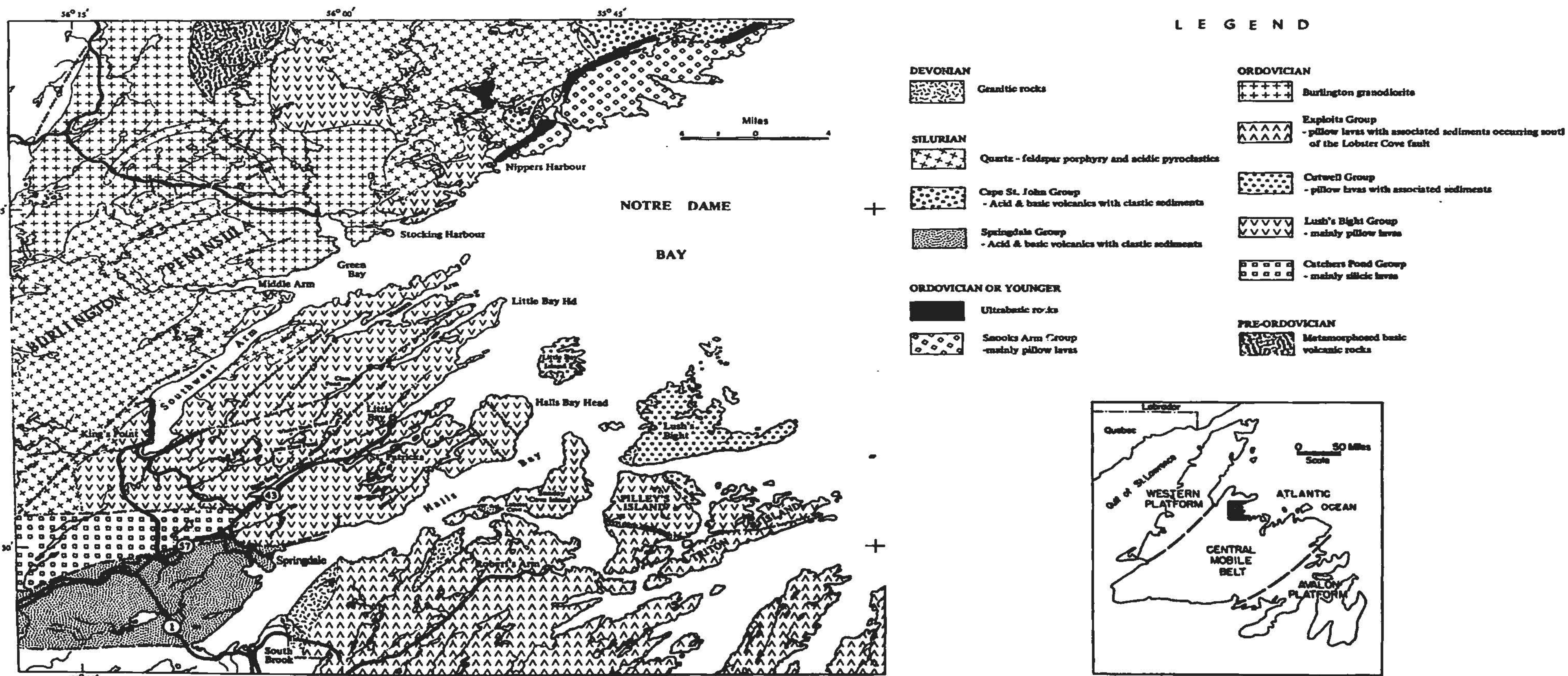

Figure 2. Geology of Western Notre Dame Bay (after Williams, 1962; Neale & Nash, 1963; Neale and Kennedy, 1967).

The rocks of the Whalesback area are part of the Lower Ordovician Lush's Bight Group which occupies a wedge-shaped area in the southwestern corner of Notre Dame Bay (see Fig. 2). The Lush's Bight Group underlies most of the Springdale Peninsula and Sunday cove Island, the northern parts of Pilley's and Triton Islands, and parts of the eastern Burlington Peninsula. The term 'Lush's Bight Group' was first applied by Espenshade (1937) to rocks exposed on Pilley's, Sunday Cove and Triton Islands. Similar rocks on the Springdale Peninsula were included in the Lush's Bight Group by Maclean (1947). The volcanic and related rocks exposed in the Nipper's Harbour - Stocking Harbour coastal area of the Burlington Peninsula were called the Nipper's Harbour Group by Baird (1951) but this term was discarded by Williams (1962) who included these rocks in the Lush's Bight Group.

Stratigraphy

Maclean (1947) divided the Lush's Bight Group into the Little Bay Head and the Western Arm sections. The Little Bay Head section underlies most of the Springdale Peninsula including the Whalesback area. It is a rather monotonous sequence of mainly pillowed basaltic rocks that have been regionally metamorphosed to the greenschist facies. Some acidic flows and pyroclastic rocks are included in the Little Bay Head section and inter-pillow chert is common. The Western Arm section, exposed north and north-east of Clam Pond and south of Western Arm, is less highly deformed, and is better preserved than the Little Bay Head section. It contains a high proportion of pyroclastic rocks and significant amounts of other sediments including chert, slate and greywacke (Marten, in preparation). The sections of the Lush's Bight Group exposed on Pilley's, Sunday Cove, and Triton Islands were correlated by Maclean (1947) with the Western Arm section.

The Lush's Bight Group has been assigned to the Lower Ordovician on the basis of one fossil, a brachiopod shell collected by Maclean (1947) from a shale bed at the bottom of the Western Arm section. It was identified as belonging to the genus *Discotreta* and Maclean (1947, p. 4) stated: "... its age is fairly definitely Canadian, probably Late Canadian." Although the Western Arm section is almost entirely bounded by faults, Maclean (1947), on the basis of structural considerations, considered it to be stratigraphically above the Little Bay Head section. Thus, much of the Lush's Bight Group must be Lower Ordovician but the possibility that the Little Bay Head section is partially Cambrian cannot be ruled out.

At its southern limits, on the Springdale Peninsula and on Sunday Cove and Pilley's Islands, the Lush's Bight Group is in fault contact with the Springdale Group, a sequence of distinctive silicic to basic volcanics with red conglomerates and sandstones, siltstones and shales (Williams, 1962; Neale and Nash, 1963). The Springdale Group is regarded as Silurian (Williams, 1967) although it has recently been suggested (Bird and Dewey, 1970) that it may be younger. A similar sequence on the Burlington Peninsula, called the Cape St. John Group, was previously correlated with the Springdale Group but is now thought to be pre-Ordovician (H. Upadhyay, personal communication). On Triton Island the Lush's Bight rocks are in fault contact with the Exploits Group of clastic sedimentary rocks, lavas and pyroclastics, also of Ordovician age.

A sequence of silicic to basic volcanics with thin beds of fossiliferous limestone, the Catcher's Pond Group, occurs at the southwestern boundary of the Lush's Bight Group where the contact relationships are uncertain. These rocks, formerly considered equivalent to the Springdale Group, have recently been shown to be Lower Ordovician (Dean, 1970).

On the Burlington Peninsula the Lush's Bight Group is bounded in most places by an intrusive quartz-feldspar porphyry with associated silicic volcanics thought to be Silurian. At Stocking Harbour and Northern Arm, Lush's Bight rocks are in-trusive contact with the Burlington Granodiorite which, on the basis of stratigraphical evidence, is considered to be Ordovician (Neale and Kennedy, 1967). Two bodies of intrusive rock occurring within the Lush's Bight Group on the Springdale Peninsula near Southwest Arm have been correlated with the Burlington Granodiorite (Neale and Nash, 1963). This interpretation has been corroborated by Sayeed (1970) who also suggested a possible genetic association between the intrusive rocks and the basic lavas.

The most seaward islands in this portion of Notre Dame Bay, Little Bay Islands and Long Island, are underlain by the Cutwell Group. These rocks, basic volcanics and sediments with some limestone, were included by Espenshade (1937) in his Lower Ordovician 'Pilley's Series' with the Lush's Bight Group. More recently, however, fossil evidence has been uncovered which strongly suggests a lower-Middle Ordovician age for the Cutwell Group (Williams, 1962).

At its most northeasterly exposures on the eastern coast of the Burlington Peninsula the Lush's Bight Group is separated from the Snook's Arm Group by a linear belt of ultrabasic rocks considered to be of Ordovician age. Recent work by H. Upadhyay (personal communication) has indicated that the Snook's Arm Group, formerly thought to be equivalent to the Lush's Bight Group, may be partly Silurian.

Structure

Within the Lush's Bight Group, especially the Little Bay Head section, a general lack of primary bedding or layering and associated features plus a lack of marker horizons makes structural determinations very difficult. The general structure of the group is, therefore, very imperfectly understood.

Maclean (1947) considered the Lush's Bight rocks on the Springdale Peninsula to have been folded into a major anticline, overturned toward the south and with its axis trending about $N67^{o}E$

through Little Bay Head. This major fold was then cut by several steeply dipping faults. Neale and Nash (1963, p. 30), however, suggested that the major structure is a "complex synclinorium whose axis trends roughly northeastward through Davis Pond." They further suggested that the synclinal axis formed the locus of the Davis Pond fault, one of the major northeasterly trending faults. Neale and Kennedy (1967) considered the Lush's Bight Group to have been first tightly folded about closely spaced axis and more openly folded later. This interpretation has been confirmed by Sayeed (1970) who also found evidence of a third, much milder, deformational phase.

The faults which cut the Lush's Bight Group are all subsidiary to, or branches of, the major fault zone which transects Western Newfoundland in a general northeasterly direction through Grand Lake. The Lobster Cove fault, which separates the Lush's Bight Group from the Springdale Group, is part of a major east-west fault zone through Notre Dame Bay. Horne and Helwig (1969) have suggested that this fault-zone separates two distinct terranes of Lower Paleozoic rocks and refer to the rocks north of the Lobster Cove fault as the 'Lush's Bight terrane'. Movement along the fault is not well understood but some evidence of dextral strike-slip movements has been found (Heyl, 1936; Kay, 1967).

The Davis Pond fault, mentioned above, is a major fault cutting through the Lush's Bight Group. It has been suggested that this fault offsets the Lobster Cove fault (Maclean, 1947; Neale and

Nash, 1963) which would require a 2 1/2 mile, dextral, lateral displacement. Other major faults are found within the Lush's Bight Group on the western portion of the Springdale Peninsula. The bulk of the evidence favors dextral movements on these faults as well (Maclean, 1947). Numerous lesser faults subsidiary to these main zones are indicated by well defined topographic linears. Many such linears are found in the Whalesback area.

Dewey (1969) and Bird and Dewey (1970) have proposed a model for Appalachian development based on expansion and contraction of a Proto-Atlantic ocean. In this model the Lush's Bight Group is envisaged as deformed oceanic crust.

CHAPTER 3

THE WHALESBACK AREA - GENERAL GEOLOGY

Introduction

Enclosed within Maclean's (1947) Little Bay Head section, the Whalesback area contains portions of three fault blocks. The central part of the area is bounded on the south by the northeasterly-trending Davis Pond fault and on the north by the more northerly trending, subsidiary Little Deer Pond fault. Considerable portions of the adjacent fault blocks were also mapped (see Fig. 1).

Two types of metabasalts have been recognized in the area. These rocks, previously given various field names such as 'andesite', 'spilite', 'dacite' and 'basalt', have been designated the 'Whalesback' and 'St. Patrick' types (Papezik, 1965; Papezik and Fleming, 1967). Occurrences of acidic rocks are rare. Some pyroclastic rocks, mainly iron-rich tuffs, have been recognized. Chert is common as inter-pillow fillings and thin, discontinuous lenses. Intrusive gabbroic rocks are present throughout the area as dykes, sills and small stocks. Younger feldspar-,amphibole-, and pyroxene -porphyry dykes are more erratically distributed.

The whole assemblage has been regionally metamorphosed to the greenschist facies. Metasomatic processes, to be considered in Chapter 6, appear to have had only very local effects. The rocks have been extensively faulted, locally sheared, and appear to have been steeply folded although the style and intensity of folding is difficult to analyze.

The Whalesback and Little Deer sulfide ore bodies are contained in shear zones north of and subsidiary to the Little Deer Pond fault. These zones are characterized by massive chloritic and, in the case of the Little Deer zone, sericitic alteration. Elsewhere in the Whalesback area mineralization is confined to small occurrences.

The general geology of the Whalesback area is shown in Figure 1 (in pocket), a compilation of the mapping of various workers. Most of the compiled data were drawn from maps by Drover (1963), Gandhi (1964), Papezik (1965) and the writer's own mapping (Fleming, 1965). The area exposed by the draining of Whalesback Pond was mapped by Taylor and Drover (1964). Some information on the area of the Whalesback chlorite zone east of Whalesback Pond was taken from a map by Cruft and Mayor (1961). The central part of the map area has been mapped only cursorily by Taylor (1966); consequently, that portion of the map is relatively less detailed. Figure 3 is an index to the maps on which Figure 1 is based.

The following discussion is based mainly on the writer's observations in that part of the Whalesback area mapped by him, the portion around Little Deer Pond. However, the similarity of the geology of the remainder of the Whalesback area to that around Little Deer Pond is indicated by other workers' observations and the petrographic and petrologic work of the writer. Therefore, the

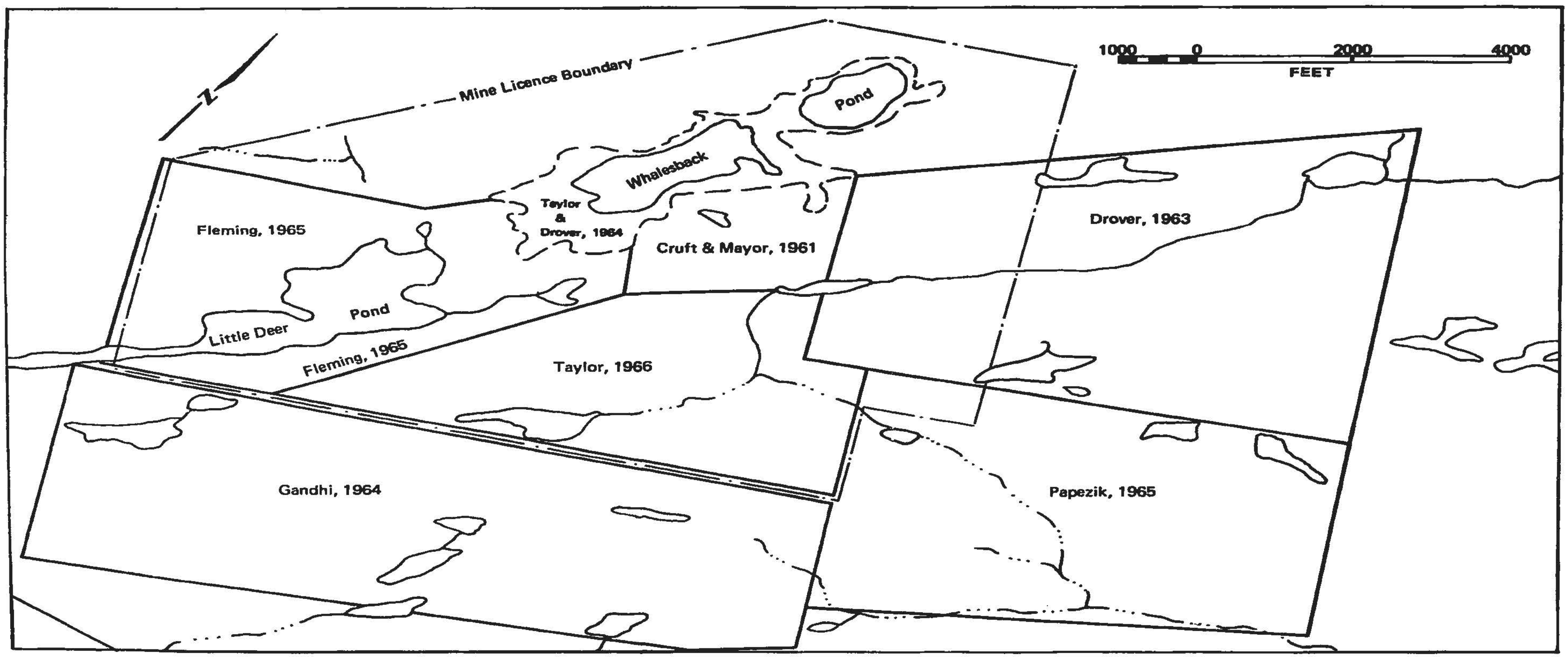

Figure 3. Index to geological mapping in the Whalesback area, Newfoundland

comments made below are believed to be applicable to the whole Whalesback area.

Principal Rock Types

Whalesback Volcanics

The term 'Whalesback Volcanics' was introduced by Papezik (1965) to describe the extensive occurrences throughout the area of rocks similar to those found in the vicinity of Whalesback Pond. These rocks underlie more than 50% of the area north of the Davis Pond fault. South of this fault only a few small exposures were noted (Gandhi, 1964; Papezik, 1965).

The most distinctive macroscopic feature of the Whalesback volcanics is their light green to greyish green color, resulting from an abundance of epidote. Most of the rocks are pillowed although some massive flows have been noted. Pillows vary in size from about 6 inches to 2 feet in diameter, usually elongated in a direction parallel to the schistosity, roughly northeast. Some zoning within pillows is evident, with epidote being accumulated at pillow centers as spherulitic aggregates or crude segregations. The pillows are highly deformed and often have a thin chloritic rim (see Plates V, VI & VII). Inter-pillow spaces are filled with a selvedge of epidote, fine grained chlorite, and white or pink (rarely red) chert. Schistosity is but faintly developed except where the rocks have been sheared.

Whalesback-type rocks are mainly aphanitic; epidote is usually the only mineral that can be identified in hand specimen. Tiny feldspar laths and small specks of chlorite, however, can sometimes be identified in a thin weathered zone which extends only 0.1 - 0.2 inches below the surface of the rock.

Rocks similar in most respects to the Whalesback volcanics, but characterized by numerous tiny (less than 1/2 mm.) black specks of chloritic material have been found southeast of Whalesback Pond by the writer and in the vicinity of Crescent Lake by Gandhi (1964) and Papezik (1965). Thin section studies have confirmed that these rocks are but a variety of the Whalesback type.

St. Patrick Volcanics

Virtually all the area south of the Davis Pond fault is underlain by flow rocks which are distinguished from the Whalesback volcanics by a relative lack of epidote and abundance of chlorite. Consequently these rocks have a very much darker green color and more highly developed schistose fabric. North of the Davis Pond fault these chloritic rocks occupy approximately 25% of the area. Because they are most extensively exposed south of the Davis Pond fault, near the village of St. Patrick's, these rocks have been called the 'St. Patrick' type.

The exposures north of Little Deer Pond are mostly pillowed and display some of the best developed pillows seen in the area; massive flows are less abundant. South of the Davis

Pond fault, however, the reverse situation was observed; there, most of the flows are massive (Gandhi, 1964; Papezik, 1965). Similarly, the St. Patrick-type flows in the northeastern part of the area were considered to be largely of the massive variety (Drover, 1963). The massive rocks are aphanitic to fine-grained. Individual grains are most easily identified in the thin weathered zone where the rocks are seen to consist essentially of feldspar laths in a chloritic groundmass. Amygdules are more common than in the Whalesback type and consist of quartz, calcite and epidote.

The pillowed variety is aphanitic although epidote is sometimes identifiable at pillow centers. Pillows are much more consistent in size and shape than in the Whalesback volcanics. They are usually 1.5 to 2 feet in diameter and more consistently approach the textbook 'bun' shape than the highly contorted pillows in the Whalesback flows (see Plates VIII & X). Elongation parallel to the schistosity is common. Some intra-pillow zoning was observed, with epidote tending to be accumulated at pillow centers; however, the much lower content of epidote makes this feature less evident than in the Whalesback rocks.

The St. Patrick-type flows are higher in iron content than the Whalesback type; this is evident from the brown to reddish iron oxide staining prevalent on fracture surfaces and is readily confirmed with a hand magnet. This feature may also be useful in mapping the two flow types since the St. Patrick type are quite well delineated on ground geomagnetic maps.

Acidic Rocks

Only a few small occurrences of acidic flow rocks were noted in the area. On the south shore of Snake Lake A and north of Snake Lake B (Fig. 1) the exposures are highly weathered and crumble easily. Quartz and feldspar grains are visible macroscopically but the rare mafic grains are unidentifiable in hand specimen (Gandhi, 1964). Gandhi called the rock 'rhyolite'. Papezik (1965) noted an occurrence of similar rock on the northwest shore of Tuff Lake.

Two occurrences of an acidic intrusive rock were mapped by Papezik (1965) south of the eastern portion of the Davis Pond fault zone. The rock was described as fine-grained and siliceous, weathering to a smooth white surface.

Pyroclastic Rocks

Rocks having an apparent clastic and/or fragmental origin occupy about 5% of the area. They seem to be much more abundant toward the eastern and northeastern margins of the map-area, although some occurrences have been noted by all workers in the area. Their absence from some parts of the area may be more apparent than real and related to poor exposure and/or less detailed mapping. This is especially true of the west central portion of the area which was only cursorily mapped.

All these rocks have been thoroughly metamorphosed and recrystallized and thus are difficult to interpret, but they are considered to be tuffs and agglomerates.

Rocks of possible tuffaceous origin are by far the most abundant of the pyroclastic types. Most of these are dark-colored, iron-rich schists characteristically quite highly magnetic. The very dark, almost black, color and well developed schistosity make these rocks easily distinguishable from the flows. They are mostly aphanitic, although a fine lamination caused by slight differences in chlorite and epidote content has been observed at some locations, e.g., on the shore of Tuff Lake in the eastern part of the area (Papezik, 1965). No lamination was observed in the small occurrences north of Little Deer Pond; however, the Whalesback-type flow rocks near the contact with the schists contain some thin (1/4") lenses of black, magnetic rock, similar to the dark schists. Locally the schists are markedly calcareous, the carbonate being present as finely divided material throughout the rock. Being the most magnetic rocks in the area, the dark schists are well delineated by magnetometer surveys. These surveys show that the inferred discontinuous distribution of the schists is probably correct. Thus, their value as marker horizons is probably limited.

Other highly schistose rocks, possibly also tuffaceous, are lighter colored, light green to grey, and only slightly magnetic or non-magnetic. Very few of these rocks have been found in surface exposures but they have been found in relative abundance in the underground workings and diamond drill cores in both the Whalesback and Little Deer shear zones. These rocks are often very finely laminated but aphanitic. Like the dark schists they are often calcareous, but unlike the former the lighter colored schists may also contain significant amounts of sericite.

The few agglomerates found are all within Whalesback-type flows. All those described by other workers are similar to the one occurrence mapped by the writer, just south of the Whalesback shear zone. This consists of fragments of Whalesback type rock 1 to 2 inches in diameter and elongated parallel to the schistosity in a dark green matrix. Both fragments and matrix are aphanitic and contain many small veinlets of epidote.

Gabbroic Intrusive Rocks

Gabbroic rocks are found in the area as dykes, sills and small stocks. They are most abundant in the central fault block, less abundant north of the Little Deer Pond fault, and only infrequently found south of the Davis Pond fault. Altogether, gabbroic rocks occupy about 20% of the area and appear to be more abundant in the Whalesback volcanics than in the St. Patrick-type flows.

In general, the gabbros are fine to medium grained rocks, massive, and often display well developed jointing. Mineralogically, they are of two main types; those found intruding the St. Patrick volcanics are chloritic and those within the Whalesback volcanics are generally highly epidotized. Thus, the two types might be termed the 'St. Patrick' and 'Whalesback' gabbros. They are not distinguished on Figure 1 because the two types were not consistently differentiated by all the workers in the area.

The gabbros intruding the St. Patrick volcanics are dark green in color and consist mainly of feldspar laths in a matrix of chlorite and amphibole. They occur as dykes and small, sill-like bodies. The association between this type of gabbro and St. Patrick volcanics has been particularly noted north of Little Deer Pond (Fleming, 1965) and south of the Davis Pond fault (Papezik, 1965), were gabbroic rocks are infrequently found. Elsewhere in the area the gabbros are usually of the 'Whalesback' type.

Within the Whalesback volcanics gabbroic rocks are usually medium grained, light greenish-grey rocks consisting mainly of feldspar and pyroxene grains in a matrix hign in epidote. Randomly distributed grains of feldspar and pyroxene give these rocks a distinctive 'salt and pepper' appearance on weathered surfaces. At some locations, however, considerable variations in composition have been noted. Papezik (1965) observed two exposures east of Corner Lake of a rock similar to the 'Whalesback' gabbro but containing a much greater proportion of pyroxene in grains up to 5 mm. in diameter. He also noted a few occurrences with grains of amphibole in a dark chloritic matrix. The 'Whalesback' gabbros occur as dykes, and sill- and/or stock-like bodies that may be up to 3000 feet long.

Younger Dykes

The 'younger dykes' are mainly porphyritic rocks containing feldspar, amphibole, and pyroxene phenocrysts, and a few dykes termed 'felsite'. These cut all the rocks of the basalt-pyroclastics-gabbro sequence but were metamorphosed and deformed with it. The dykes occur in abundance north of the Little Deer Pond fault but are rarely observed south of the fault. They vary in width from several inches to several feet and trend generally either northwest or slightly east of north. Some of the dykes, particularly within the shear zones, have been deformed into elongated boudin-like shapes.

The feldspar, amphibole, and feldspar-amphibole types are the most common of the porphyry dykes. In some the grains are highly fractured and broken and these appear to be intrusive breccias. The pyroxene porphyry dykes consist of highly altered pyroxene phenocrysts in an aphanitic groundmass.

In view of their similarity and close association it is likely that all the porphyry dykes are related and originated from a common source.

The felsite dykes are aphanitic, grey, and relatively hard rocks. These are not common in the area but have been found mainly in the vicinity of the Whalesback shear zone and are frequently observed in the underground workings.

Structure

General Statement

Because of the generally poor exposure and the scarcity of primary features from which the attitude of flows could be determined it has not been possible to determine the intensity and style of folding. However, in some better exposed parts of the area, some features such as bedding in pyroclastic rocks, compositional banding, and relatively undeformed pillows have been noted. A study of the structural character of these rocks should adopt a more regional approach than was used in the present study, concentrating on areas of good exposure, especially coastal exposures.

Compositional Banding

Compositional banding was observed by the writer in three separate exposures north of Little Deer Pond (see Fig. 1). The banding occurs in massive rocks and is caused by slight differences in epidote content which differential weathering reveals as regular bands about 3 inches thick (see Plate IX). No examples of this type of structure were reported by any of the other workers in the area.

The banding occurs in two exposures of Whalesback-type rocks; one is on the Mine Licence Boundary line about 500 feet north of Little Deer Pond, the other about 300 feet north of Bog Pond. The third example occurs within St. Patrick volcanics about 500 feet northeast of the western Mine Licence Boundary line. The presence of this structure may indicate that these rocks are intrusive; however, since they are similar to flows in every other respect and are small bodies, at any rate, they are indicated as flows in Figure 1.

The banding is probably a primary structure akin to flow banding and thus indicative of the attitude of the rocks. This is suggested by the fact that the three cases of banding observed, which are within 1600 feet of each other, are subparallel. Also, in the most northerly example, the attitude of the banding is parallel to that of well-formed pillows in the same exposure.

Pillows

Although locally abundant, especially in the Whalesback-type flows, pillows are seldom usable in the determination of flow attitudes. In many cases the pillowed nature of flows is only inferred from the rounded, hummocky nature of outcrops (see Plate V).

In the Whalesback-type lavas pillows are highly deformed. Where seen in sections perpendicular to the schistosity they are ellipsoidal in shape and flattened in the plane of schistosity. In the rare cases where they are seen in sections parallel or subparallel to the schistosity the pillows present a great variety of shapes moulded against each other indicating at least some deformation while still in a plastic condition (see Plate VI). Thus, the few cases where the classic 'bun' shapes are seen may be purely fortuitous. Nevertheless, localities where pillows give a good indication of flow tops are marked on the accompanying geological map (Figure 1).

Pillows in the St. Patrick-type flows, although less widespread then in the Whalesback flows, are more consistent in size and shape and less deformed. Typical pillow structures in the St. Patrick rocks are shown in Plates VIII & X. They are flattened in the plane of the schistosity but where seen in sections parallel to the schistosity the classic 'bun' shapes are consistently observed. Unfortunately, good sections parallel to the schistosity are rarely found.

Schistosity

Only one general direction of schistosity was noted by most workers in the area. It is but faintly developed in the Whalesback-type flows, more pronounced in the St. Patrick volcanics, and well developed in the tuffaceous rocks.

The direction of the schistosity is generally about N60^{o}E but toward the eastern corner of the area some more northerly directions were recorded (Papezik, 1965). Dips are usually to the northwest and vary from about 60^{o} to vertical.

A southeasterly trending, vertically dipping schistosity was recorded by Gandhi (1964) southeast of Snake Lake C. Its form or significance were not discussed.

Jointing and Fracturing

Jointing is well developed only in the gabbroic intrusive rocks, and is characteristic of those rocks. Spacing of joints varies from about 6 inches to 3 feet. Several conjugate sets of joints were recorded but no consistent pattern could be discovered.

Irregularly developed fractures are everywhere present but fracturing is only intense in and near fault zones.

In the western corner of the area, on the south side of the east-trending fault north of Little Deer Pond, are numerous horizontal, quartz-filled fractures with a sigmoid shape. These are probably related to the faulting, indicating some vertical movement.

Faulting and Shearing

Two major faults, the Davis Pond and Little Deer Pond faults, cut the Whalesback area into three fault blocks. Minor faults are numerous. All are marked by distinct topographic lineaments developed on zones of shearing or intense fracturing.

The Davis Pond fault, a branch of the major fault system transecting Western Newfoundland, cuts the southern part of the areas; its strike averages about N55^{o}E. For most of its length it can only be mapped as a zone, 300 to 500 feet wide, in which the rocks have been highly sheared and fractured. Its course is marked by a very pronounced valley with small, elongated lakes.

The Little Deer Pond fault is subsidiary to the Davis Pond fault, branching from it in a more northerly direction at Davis Pond, to the southwest of the Whalesback area. In the Whalesback area it trends about N45^{o}E along a prominent valley part of which is occupied by the long arm of Little Deer Pond. Near the fault the rocks are highly sheared and fractured but the zone of intense deformation does not appear to be as wide or pronounced as is the case with the Davis Pond fault.

Several other smaller-scale faults parallel or subparallel to the Davis Pond and Little Deer Pond faults have been mapped. Notable examples are the fault trending northeasterly from Crescent Lake, the fault through Bouzanne's Pond, and the one forming the northern border of the mapped area east of Whalesback Pond.

All the other minor faults trend roughly easterly or somewhat south of east to meet the major faults obliquely. The vast majority of these are located in the fault block north of the Little Deer Pond fault.

Faulting on a smaller scale but with a northerly trend was noted by Papezik (1965) south of the Davis Pond fault.

Minor shearing has been noted as accompanying faulting and is also seen at other locations. Two very pronounced shear zones occur on the north side of the Little Deer Pond fault and appear to be subsidiary to it. These are zones of intense alteration with a rather sinuous trend, slightly north of east; one through Little Deer

Pond and the other through the western end of Whalesback Pond. Both dip steeply to the south. These zones contain the Whalesback and Little Deer ore bodies. Both occur within Whalesback-type lavas and contain highly altered rocks, similar to the Whalesback volcanics, with relict pillows. However, the Little Deer Zone contains a high proportion of pyroclastic rocks and some are also present in the Whalesback zone.

The abundance of minor faults and shears north of the Little Deer Pond fault indicates that this block has experienced greater movement than the blocks to the south. More fracturing in this block is also indicated by the prevalence of porphyritic dykes there. Movement of the block as a whole was probably accomplished along the easterly-trending minor faults and shears. The easterly-trending pattern of the minor faults and shear zones suggests dextral movement of the whole block. No direct evidence of the direction of movement was obtained.

Papezik (1965) suggested that the pattern of faulting and shearing associated with the Davis Pond fault indicates dextral movements. He also found some slickensides on minor fault planes south of the Davis Pond fault with the striae plunging 30° to 40° confirming a considerable strike-slip component on the subsidiary faults.

Folding

On the basis of the sparse data collected little can be said about the nature of folding in the area. In the eastern part of the north fault block, changes in dip from steeply northwestward to overturned southwestward have been recorded within 100 feet, indicating tight folding. In the western part of this fault block, however, shallow to moderately steep northwestward dips are indicated by compositional banding and pillows. Elsewhere in the area the attitudes of laminated schists, sill-like intrusives, and pillows indicate consistently steep dips, usually to the northwest.

Some speculations on the overall structure can be made, although only on the basis of indirect evidence. The St. Patrick volcanics appear to be the last known products of differentiation in a Whalesback-St. Patrick series (see Chapter 6). This suggests that the St. Patrick rocks are stratigraphically higher than the Whalesback volcanics. This stratigraphic sequence is also suggested by the prevalence of gabbroic rocks in the central part of the area, underlain mainly by Whalesback volcanics, indicating that this is a stratigraphically lower portion of the sequence than the rocks to the north of the Little Deer fault and south of the Davis Pond fault. The distribution of the St. Patrick volcanics mainly toward the northern, southern and western margins of the area, then, suggest a possible westward plunging anticlinal structure.

CHAPTER 4

ECONOMIC GEOLOGY

Introduction

The presence of sulfide mineralization at Whalesback Pond was known as far back as 1885, and in 1921 a shaft was sunk in the hanging wall to a depth of 60 feet (Peters, 1967). British Newfoundland Exploration Limited (Brinex) began their evaluation of the deposit in 1960, in the course of an investigation of the Hall's Bay region. The deposit was outlined by geochemistry and various geophysical methods, including vertical and horizontal loop E.M., magnetometer, and self potential. Drilling was begun in February 1961, a development licence was obtained in 1962, and the shaft was collared in the fall of 1962. Development and construction were carried out over the period 1963-1964; the lake was drained in the summer of 1964. Production was commenced in 1965.

The Little Deer deposit was similarly outlined by geochemical and geophysical surveys over Little Deer Pond in 1961 along the projection of surface mineralization on the northern shore of the pond. Some drilling was carried out in 1961 and was resumed in 1966. Development was begun in 1967 by means of a drift from the Whalesback mine on the 800 foot level. Some production is being achieved through the Whalesback mine facilities, in the course of continuing development.

The Whalesback deposit is the most intensively studied of the two, having been the subject of a comprehensive investigation by the Geological Survey of Canada. Some results of this study have been published by Kanehira and Bachinski (1968).

Whalesback Deposit

Within the highly chloritized shear zone most of the rocks resemble the Whalesback-type flows but some pyroclastic rocks have been recognized (V.S. Papezik, personal communication). Gabbroic intrusives and porphyry dykes are abundant.

In their detailed study of the ore zone, Kanehira and Bachinski (1968) found that the intensity of alteration increases from footwall to hanging wall and the ore is confined to the more highly altered central and hanging wall portions of the zone. The ore, veins and pods of disseminated sulfides, consists of pyrite, chalcopyrite, pyrrhotite, sphalerite, mackinawite, pentlandite, magnetite, cubanite, galena, and ilmenite, in order of abundance. Marcasite, covellite and goethite are present as supergene minerals. The most abundant gangue minerals are chlorite and quartz with some muscovite, carbonates, sphene, albite and epidote.

Kanehira and Bachinski (1968) observed that the porphyritic dykes cut the shear zone and the sulfide ore but regional metamorphism has affected both dykes and ore. Nevertheless, many of the porphyritic dykes were found to be broken and stretched into boudins, indicating post-dyke movements within the zone. They concluded (Kanehira & Bachinski, 1968, p. 1395): "Sulfide mineralization, then, must be post-volcanic lavas, in part pre-shearing, and pre-regional metamorphism."

Little Deer Deposit

The Little Deer shear zone is roughly parallel to the Whalesback zone. West of Little Deer Pond the zone trends about N65°E but beneath the pond it is sharply offset to the southeast, possibly by folding (Peters, 1967).

The shear zone occurs within Whalesback-type lavas; in the highly altered zone, however, the rocks are mainly quartz-sericite-chlorite schists of probable pyroclastic origin. An agglomeratic horizon has been found to occur along much of the hanging wall at depth (Peters, 1967). Like the Whalesback zone, the Little Deer deposit, is also cut by porphyritic dykes. The principal ore minerals in order of abundance are pyrite, pyrrhotite, chalcopyrite and sphalerite. Gangue minerals include quartz, calcite, sericite, and chlorite.

Formation of the Deposits

Although there are some significant differences between the Whalesback and Little Deer ore zones, their close spatial association, structural similarity and occurrence within similar rocks strongly suggest a common origin. Also, the fact that the

Little Deer zone is cut by porphyritic dykes suggests that the mineralization there occurred simultaneously with that in the Whalesback zone. The presence of pyroclastic rocks in both zones suggests that the locations of these rocks might have determined the locations of shearing and sulfide deposition; whereas the more rigid flows yielded to stresses by faulting the pyroclastic rocks might have yielded by shearing and, in the case of the Little Deer zone, perhaps folding. These sheared pyroclastics, more porous and permeable than the surrounding rocks, would be logical depositional sites for sulfide minerals, whatever their ultimate origin.

CHAPTER 5

PETROGRAPHY OF THE LAVAS

Methods Used

Most of the seventy thin sections examined during the course of this study were from rocks exposed within the area mapped by the writer (see Fig. 3) but some from the southern part of the Whalesback area, mapped by Gandhi (1964), were also included. In addition, the writer was given access to more than two hundred thin sections described by V.S. Papezik. Among this collection were representative rocks from all parts of the area and some from Lush's Bight Group rocks elsewhere on the Springdale Peninsula.

In the petrographic work, emphasis was placed on the Whalesback and St. Patrick types of flow rock because they had proved to be the only units into which the flows, the most abundant rocks of the area, could be subdivided; a thorough knowledge of them was required to make their distinction in the field meaningful. These rocks constituted the bulk of the thin sections examined and on these only were any more refined techniques, such as universal stage and X-ray diffraction techniques, employed. Petrographic investigation of the other rock types was confined to examination under the ordinary petrographic microscope. In all cases, modes were estimated visually. Point counting was not feasible because the rocks are too fine grained and too highly altered.

Plagioclase compositions were determined first on the flat stage by the extinction method on a few grains in every thin section. The results were confirmed and refined by measurements on selected grains in representative thin sections using a Leitz five-axis universal stage. The method of Slemmons (1962) was used where possible to determine composition and structural stage. Because Slemmons' method requires the presence of a recognizable cleavage or transverse composition plane, not often observed in the rocks studied, the Federov-Nikitin curves (Reinhard, 1931) were used to determine the type of twin being measured and as a check method. Only if the compositions obtained from both methods agreed closely were the results considered usable.

The optic axial angle (2V) was the only parameter measured in the identification of clinopyroxene. N_y could not be measured because of the difficulty of separating the very small (approx. 0.5 mm.) grains which are, in any case, often altered to amphibole; thus only the approximate calcium content was determined. The 2V was determined by estimation of optic axis and acute bisectrix figures where possible and, as in determining plagioclase, the results were checked by measurements on the universal stage.

X-ray diffraction techniques were used in an attempt to determine approximate chlorite compositions. Suitable chlorite concentrates were obtained by magnetic separation of -100 and +150 mesh crushed fractions. Concentration was achieved on the Franz magnetic separator; the magnetic fraction obtained at 0.4 amps, having first separated out a more magnetic fraction at 0.2 amps, was found to be most adequate in that it gave the strongest and best defined chlorite peaks.

A measure of the heavy atom content ($Fe^{2+} + Fe^{3+} + Mn^{2+} + Cr^{3+}$) of chlorite in four specimens each of the Whalesback and St. Patrick volcanics was made by determining the relative intensities of X-ray diffracted from the basal planes according to the method of Petruk (1964). Average peak intensities obtained in three replicate runs for each specimen, on a Phillips diffractometer using CuKα radiation, were used. The Al^{3+} content of chlorite was determined by measuring d(001) as described by Albee (1962). The d(001) spacing was determined indirectly by measuring d(004) using the quartz ($10\bar{1}1$) peak as a standard, and taking 4 X d(004) to equal d(001).

Whalesback Volcanics

Mineralogy

The rocks of the Whalesback type consist essentially of microphenocrysts of albite and augite in a groundmass comprising albite, epidote, chlorite, amphibole and leucoxene (Plate XI A). The following is an average estimated mode:

Albite	35%
Augite	15%
Epidote	30%
Chlorite	10%
Amphibole	5%
Opaques	5%

Microphenocrysts normally constitute 10 - 15% of the rock. Quartz and calcite are present as minor constituents.

Randomly distributed, subhedral to anhedral plagioclase microphenocrysts, 1 mm. or less in length, are clouded with minute inclusions and have indistinct, highly embayed outlines (Plate XI, A & B). Bent and/or broken grains showing signs of strain are frequently observed. Twinning is not common and is usually simple in the microphenocrysts. In the groundmass, plagioclase is present as randomly oriented microlites (approx. 0.25 mm. long), resembling the microphenocrysts but more commonly twinned. Twinning appears to be mainly of the Albite type but Manebach and Carlsbad twins were also identified. Twins are usually simple or, if multiple, few lamellae are present. Despite this the twinning displays most of the characteristics of the secondary type described by Vance (1961); i.e., lamellae are slender and uniform, bend with the grain and commonly terminate against fractures or taper out gradually (Plate XI B). The plagioclase, both microphenocrysts and groundmass microlites, varies in composition from An_5 to An_{10} and is of the 'plutonic' or low-temperature variety.

Clinopyroxene is usually present only as microphenocrysts; smaller grains in the groundmass are rare. The grains are usually subhedral, colorless, and are frequently twinned. Many grains are partially or wholly altered to fibrous, pale green actinolite or chlorite (Plate XII, A & B). The 2V varies from 48^o to 51^o, averaging 50^o. This, with the pale color indicating moderate iron content, identifies the mineral as calcic augite.

Epidote, second only to plagioclase in abundance, occurs as tiny, anhedral grains (1/2 mm. or less in diameter) either randomly distributed or forming aggregates which may be identifiable macroscopically. A turbid appearance is imparted by the presence of numerous dust-like inclusions of leucoxene, usually more abundant at grain edges (Plate XIII, A & B). Epidote is also commonly present in tiny veinlets and amygdules where it is often accompanied by quartz and/or chlorite, less frequently calcite. There, the epidote is usually coarser grained (up to 1 mm. in diameter), often sheaflike, and less cloudy (Plate XIV, A & B). No pumpellyite was recognized.

Chlorite and amphibole are very intimately associated as platy and fibrous intergrowths in the groundmass. Chlorite is also frequently present in irregular patches up to 1/2 mm. in length, and in veinlets and amygdules. The pale green, slightly pleochroic chlorite is characterized by a very low 2V (almost isotropic) and anomalous dark blue and, less commonly, dark brown interference colors. According to Albee (1962) the anomalous brown and blue interference colors indicate optically positive and negative chlorites, respectively, the latter being higher in iron. The 2V varies with Fe/Fe + Mg, the sign change occurring at a value of Fe/Fe + Mg of about 0.52. The heavy atom (mainly iron) and aluminum contents of the chlorite in four specimens as determined by X-ray diffraction are given in Table 1.

Table 1

Specimen No. *	Fe in chlorite (atoms per 10 cations)	Al in chlorite (atoms per 10 cations)
F40-65 (10)	2.0	2.6
F193-65 (11)	1.0	2.6
F36-65	1.4	2.6
F63-65	1.3	2.6
	1.4 ± 0.4	2.6

*Nos. in brackets refer to chemical analyses - see Chapter 6.

Without knowing how Al^{3+} is partitioned between the tetrahedral and octohedral layers the data in Table 1 cannot be used to precisely classify the chlorites. The Al^{3+} contents determined, however, fall within the range for chlorite in greenschists as tabulated by Albee (1962). Albee did not determine the range of total Fe in chlorites but only Fe^{3+}; however, if Fe^{2+}/Fe^{3+} in the chlorite is approximately the same as in the whole rock then the data for iron in Table 1 are also consistent with that for greenschists in general. The anomalous brown and blue interference colors indicate that Fe/Fe+Mg is approximately 0.5. The chlorites in the Whalesback-type rocks, then, probably are in the middle range of chlorites on Hey's (1954) classification, i.e., in the ripidolite or pycnochlorite fields.

The amphibole is a pale green, fibrous type, probably actinolite, interwoven with chlorite in the groundmass. Because it is so finely divided its relative abundance is difficult to assess and it may well be more abundant than has been estimated.

By far the most abundant opaque mineral is leucoxene which is distributed throughout the rocks as very finely divided, dust-like, material. The concentration of leucoxene in, and particularly at the edges of, epidote grains has been noted. A few pyrite grains, often altered to limonite, are present in most thin sections and magnetite grains have been observed in a few rocks.

Quartz and calcite are present mainly in amygdules and veinlets but tiny grains of both are very infrequently found in the groundmass of the rocks. A finely divided mineral, with a moderately high birefringence, is present but rarely as an alteration product on plagioclase. In view of the low potash content of these rocks (see Chapter 6) where sericite is unlikely to occur, this mineral may be prehnite or scapolite.

Textures

The present mineral assemblage of the Whalesback volcanics is a low-grade metamorphic assemblage characteristic of the greenschist facies. Clinopyroxene is probably the only relict mineral; metamorphic clinopyroxenes are characterized by high 2V-angles, in the diopside-hedenbergite range (Poldervaart, 1953), and begin to appear only in the amphibolite facies (Miyashiro, 1968). The extent to which the present textures resemble the original textures is a subject for speculation but their igneous appearance and the preservation of undeformed amygdules indicates that the primary textures (microporphyritic to intersertal) have been at least partly preserved in the present rocks.

St. Patrick Volcanics

Mineralogy

In contrast to the mainly pillowed Whalesback volcanics, the St. Patrick volcanics include significant amounts of both pillowed and massive varieties. These differ in texture but are mineralogically similar, with an average estimated mode as follows:

Albite	45%
Epidote	5%
Chlorite	25%
Amphibole	20%
Opaques	5%

Clinopyroxene is a minor constituent of the massive rocks only; quartz and calcite occur in small amounts in both pillowed and massive rocks.

Plagioclase in the pillowed and massive St. Patrick rocks differs mainly in grain size. In the pillowed rocks plagioclase grains seldom exceed 0.25 mm. in length but in the massive variety grains are generally 0.25 - 0.50 mm. in length, locally up to 1 mm.

(Plate XV, A & B). In both cases the plagioclase is much like that in the Whalesback volcanics, clouded with inclusions, bent and/or broken, and strained. In some of the more schistose rocks plagioclase may be approximately oriented in the direction of schistosity (Plate XVI, A). Twinning is also similar to that in Whalesback plagioclase, generally similar to the secondary type described by Vance (1961). Universal stage measurements yielded a slightly greater range of compositions than in the Whalesback rocks, An_3 - An_{10}.

Clinopyroxene occurs only in the massive rocks and then in minor amounts, although locally it can constitute up to 5% of the rock. The small grains (0.25 mm.) are usually highly altered to fibrous actinolite. The 2V averages about 50°; this and the pale color indicate a calcic augite similar to that in the Whalesback rocks.

Epidote is a relatively minor constituent of the St. Patrick rocks where it occurs as small (less than 0.25 mm.) grains, randomly distributed. As in the Whalesback volcanics it is usually highly clouded with leucoxene inclusions. One example of apparent twinning in epidote was observed (Plate XVI, B). Epidote is also present in veinlets and amgydules (Plate XVII, A & B) either alone or with quartz, chlorite or calcite.

Chlorite in the St. Patrick volcanics occurs in much the same manner as in the Whalesback-type flows and is similarly almost isotropic with anomalous brown and blue interference colors. In the

St. Patrick rocks, however, chlorite is more abundant and, also is darker colored and more pleochroic. The Fe and Al contents as determined in four specimens by X-ray diffraction are given in Table 2.

Table 2

Specimen No. *	Fe in chlorite (atoms per 10 cations)	Al in chlorite (atoms per 10 cations)
A9-6-2 (2)	1.6	2.6
F125-65 (3)	1.7	2.6
F195-65 (4)	1.0	2.6
F199-65 (6)	1.7	2.6
	1.4 ± 0.3	2.6

*Nos. in brackets refer to chemical analyses - see Chapter 6.

The darker color and stronger pleochroism of the St. Patrick chlorites, in contrast to the pale colors common in the Whalesback-type rocks, suggest that they are higher in iron. The X-ray studies were carried out primarily with a view to confirming this. The data obtained, however, indicate no appreciable differences between the Fe or Al contents of the chlorites in the two flow types. In view of the observed optical differences this probably indicates that the X-ray method, as applied here, is not sufficiently precise. There are a number of factors which could contribute to the apparent imprecision. The number of samples studied was small; a larger number of samples might indicate small average differences between the two flow types. One variety of chlorite might have been concentrated more than the other during sample preparation, although this is considered improbable. Background reflections were rather high, probably the result of using Cu-radiation with high-iron concentrates; the background might be reduced by using Co-radiation which, unfortunately, was not available to the writer at the time the work was done.

Under the circumstances only the same general conclusions about the classification of chlorite in the St. Patrick volcanics can be made as in the case of the Whalesback-type rocks. On Hey's (1954) classification, they probably fall in the ripidolite or pycnochlorite fields.

The amphibole in the St. Patrick volcanics is finely divided, fibrous actinolite. It occurs mainly in the groundmass where it is intimately intergrown with chlorite so that its abundance is difficult to estimate. In the massive flows, amphibole also occurs as an alteration product on clinopyroxene grains. Like chlorite, the amphibole is darker colored and more pleochroic than its counterpart in the Whalesback volcanics, indicating a higher iron content.

Leucoxene is the most abundant opaque mineral and occurs as very finely divided dust-like material throughout the rock. Pyrite grains are somewhat more abundant than in the Whalesback rocks. Grains of magnetite are sometimes observed in the massive rocks only.

Tiny grains of quartz and calcite are very infrequently seen. These minerals most commonly occur in amgydules and occasionally in tiny veinlets.

Textures

The St. Patrick volcanics have been more thoroughly recrystallized and are more equigranular than the Whalesback rocks. Essentially, both massive and pillowed varieties consist of albite laths in a matrix of chlorite and amphibole, the massive type being slightly coarser grained. The textures of both varieties are intersertal, locally approaching subophitic.

Pyroclastic Rocks

Most of the pyroclastic rocks mapped in surface exposures are of the iron-rich, schistose variety which cause many of the small magnetic anomalies in the area. These consist mainly of small (less than 0.25 mm.) grains of quartz and feldspar with some epidote and calcite in a chloritic matrix with abundant, finely divided leucoxene and grains of magnetite (Plate XVIII A). Epidote is sometimes roughly segregated in forms which suggest fragments (Plate XVIII A). In some places, such as on the shore of Tuff Lake, a laminated appearance is imparted by the presence of layers composed mainly of granular epidote. Another variety noted by the writer within the St. Patrick rocks north of Little Deer Pond consists of sericitized feldspar grains in a chloritic matrix with some calcite and very abundant leucoxene (Plate XVIII B).

The lighter-colored, non-magnetic chlorite and chlorite-sericite schists have been found mainly in the Whalesback and Little Deer shear zones where they are the host rocks of the sulfide mineralization (Plates XIX, A & B; XX, A). Pale green chlorite, usually with anomalous blue interference colors, is a major constituent of all these rocks in amounts varying from 30% to 60%. Granular quartz is also always present in amounts up to 30%. Sericite is more variable; it is only a minor constituent of many schists but may be present in amounts up to 25% in the Little Deer zone. Albite has been noted in relatively few of the schists but may comprise up to 25% of some of the rocks. Small amounts of leucoxene and calcite are always present.

Very few examples of agglomerate-like rocks have been observed. The only exposure examined by the writer is that south of the Whalesback zone. The fragments are similar to the Whalesback volcanics and these are set in a matrix consisting mainly of elongated aggregates of finely granular quartz and patchy chlorite. These aggregates are outlined by thin concentrations of dust-like leucoxene giving the distinct impression of shards or small fragments (Plate XX, B). Some randomly distributed epidote is present. Calcite is a minor constituent.

Gabbroic Intrusive Rocks

Mineralogically, the gabbroic rocks are very similar to the flows; hence, the difficulty in distinguishing between sill or stock-like intrusive rocks and massive extrusives, except where cross-cutting relationships are seen. In a chemical study, however, the distinction may not be important since extrusive and shallow intrusive rocks from the same source would not differ greatly.

Petrographically, the main difference between the intrusive and extrusive rocks is one of grain size. Plagioclase laths and clinopyroxene grains in the gabbros are up to 2 mm. across. The plagioclase is mainly albite but compositions up to An_{30} have been noted. The clinopyroxene is augite similar to that in the flow rocks.

The intrusive rocks found in the Whalesback and St. Patrick volcanics, respectively, differ in their relative amounts of epidote, chlorite and amphibole in much the same way as the flows. Granular, cloudy epidote is more abundant in the 'Whalesback' gabbros where the chlorite and amphibole is pale green or colorless and only weakly pleochroic (Plate XXI, A). The 'St. Patrick' gabbros contain little epidote, but green pleochroic chlorite and actinolite are relatively abundant (Plate XXI, B).

Younger Dykes

The most abundant rocks in this category are the porphyritic dykes which have been classified into four varieties containing, respectively, phenocrysts of feldspar, amphibole, amphibole and feldspar, and pyroxene.

The phenocrysts in many cases have been partially or completely altered; feldspar to clusters of epidote, sericite and calcite, amphibole to chlorite, and pyroxene to actinolite (Plate XXII, A & B). The groundmass is similar in many of the dykes, consisting of fine grained intergrowths of plagioclase, epidote, chlorite, amphibole and leucoxene; however, feldspar is notably lacking in the pyroxene-bearing varieties which contain more abundant actinolite and chlorite. The amphibole phenocrysts, often better preserved than the feldspar and pyroxene, are hornblende. Where less altered, the pyroxene is a high 2V variety, diopside or salite. A variety of the amphibole porphyry type has been noted in which the amphibole forms fragments of 'hornblendite' up to 1 inch or more in diameter.

The porphyritic dykes are probably lamprophyres of the camptonite variety. While feldspar phenocrysts are not common in such rocks, they are not unknown and the similarity of the feldspar-bearing types in the Whalesback area to the other porphyritic dykes suggests a common origin. Lamprophyres are commonly associated with granitic rocks (Turner & Verhoogen, 1960) and in the Whalesback area they may be related to the quartz diorite encountered in deep drilling in the Whalesback mine.

Aphanitic, grey-green dyke rocks found in the Whalesback mine and vicinity have been given the field name 'felsite'. These rocks consist of plagioclase microlites in a groundmass of finely divided sericite, chlorite, epidote, calcite and leucoxene. The plagioclase is highly altered to sericite and its composition cannot be determined. These rocks are clearly acidic but in view of their highly altered nature they cannot be properly classified without chemical data.

Metamorphism

The albite-epidote-chlorite-actinolite-leucoxene mineral assemblage in the mafic rocks of the Whalesback area is characteristic of the greenschist facies of regional metamorphism. However, these rocks are characteristically low in potash, and in the absence of pelitic rocks where biotite might be expected to occur, the grade and type of metamorphism cannot be determined with accuracy.

Miyashiro (1968) has noted that in all types of regional metamorphism of mafic rocks the transition from greenschist to higher facies is marked by the appearance of blue-green hornblende. This applies to the transition from greenschist to amphibolite facies, in the case of the low-pressure andalusite-sillimanite type of metamorphism, as well as to the transition from greenschist to epidote-amphibolite facies in the case of the higher-pressure, kyanite-sillimanite and jadeite-glaucophane types of metamorphism. In many cases, such as in the Central Abukuma Plateau of Japan and in Northern Michigan, blue-green hornblende may begin to appear in the higher grade portion or biotite zone of the greenschist facies (Miyashiro, 1968). The absence of blue-green hornblende from the Whalesback area and, apparently, from other rocks of the Lush's Bight Group on the Springdale Peninsula (MacLean, 1947; Sayeed, 1970), places an upper limit on the grade of metamorphism. Thus, the almandine zone and, probably, the upper part of the biotite zone may not have been reached on the Springdale Peninsula.

CHAPTER 6

PETROLOGY

Chemistry of the Lavas

Methods Used

Seventeen complete or almost complete analyses of rocks within the Whalesback area and similar rocks in adjacent areas were obtained during the course of this study. These analyses were previously reported by Papezik and Fleming (1967) and are reproduced in Table 3 with their respective norms. Included are six complete analyses of St. Patrick volcanics (nos. 1-6) and five of the Whalesback volcanics (nos. 8-12). In addition, one specimen of each type (nos. 7 & 13) was analyzed for the major oxides but ferric and ferrous iron were not distinguished, water was determined as 'loss on ignition', and TiO_2, P_2O_5, MnO, CO_2 and S were not determined. Three specimens of gabbroic rocks (nos. 14-16) and one specimen from the highly altered host rocks of the Whalesback mineralized zone were also analyzed. Seven of the complete analyses (nos. 2, 5, 6, 11, 12, 14 & 17) were performed by classical silicate methods; the others were determined by rapid chemical methods. The analysts and laboratories are listed in Table 3.

In an attempt to obtain more data on what seemed at first glance to be the major differences between the two flow types, ten specimens were analyzed by the Newfoundland Mineral Resources Division

Table 3
Analyses of Rocks from the Whalesback
and Adjacent Areas

	1	2	3	4	5	6	7	8
SiO_2	51.00	53.82	49.60	55.65	51.12	54.55	54.00	54.65
TiO_2	1.12	1.25	1.03	1.02	1.17	1.09	n.d.	0.80
Al_2O_3	14.20	15.52	14.80	14.00	14.89	16.08	15.83	15.30
Fe_2O_3	3.30	2.56	2.75	2.68	2.84	3.33	12.01*	1.87
FeO	9.08	9.30	9.40	8.36	9.29	7.53	n.d.	6.60
MnO	0.16	0.17	0.19	0.16	0.20	0.16	n.d.	0.10
MgO	5.95	3.85	6.50	5.60	5.38	4.01	5.28	7.85
CaO	6.64	6.12	5.15	4.40	5.73	5.24	5.70	4.70
Na_2O	3.88	3.80	3.47	4.62	4.50	4.36	4.52	4.72
K_2O	0.04	0.08	2.40	0.04	0.08	0.05	0.17	0.72
P_2O_5	0.11	0.21	0.22	0.22	0.18	0.12	n.d.	0.15
CO_2	1.53	0.02	1.05	0.57	0.10	0.17	n.d.	0.00
H_2O+	2.54	2.56	2.60	2.44	3.44	2.67	2.40**	1.58
H_2O-	n.d.	0.12	n.d.	n.d.	0.19	0.11	n.d.	n.d.
S	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	99.27	99.38	99.16	99.76	99.11	99.47	99.91	99.04

Norms (C.I.P.W.)

	1	2	3	4	5	6	7	8
q	4.31	8.01	-	7.67	0.52	8.23		-
feld	54.27_{an39}	57.68_{an43}	61.01_{an29}	56.11_{an30}	58.74_{an34}	61.32_{an39}		62.62_{an29}
ne	-	-	-	-	-	-		-
di	1.12	3.24	-	-	5.41	-		3.21
hy	27.73_{en47}	22.00_{en35}	18.47_{en47}	26.71_{en47}	24.86_{en43}	20.33_{en43}		27.10_{en60}
ol	-	-	9.38_{fa62}	-	-	-		1.00_{fa48}
mt	4.78	3.71	3.98	3.88	4.11	4.82		2.71
hm	-	-	-	-	-	-		-
il	2.12	2.37	1.95	1.93	2.22	2.07		1.51
py	-	-	-	-	-	-		-
ap	0.25	0.48	0.50	0.50	0.41	0.27		0.34
cc	3.47	0.04	2.38	1.29	0.22	0.38		-
cor	-	-	0.08	0.20	-	-		-
salic	58.59	65.69	61.10	63.99	59.26	69.56		62.62
femic	39.50	31.86	38.64	34.34	37.26	27.89		35.89

*Total Fe as Fe_2O_3 **Loss on ignition n.d. - not determined

Table 3 (continued)
Analyses of Rocks from the Whalesback
and Adjacent Areas

	9	10	11	12	13	14	15	16	17
SiO_2	50.20	53.15	51.23	47.52	52.00	48.23	51.10	51.00	38.67
TiO_2	0.80	0.66	0.70	0.87	n.d.	0.76	1.67	0.68	1.06
Al_2O_3	14.85	14.40	15.37	16.67	16.00	16.01	14.80	16.00	18.97
Fe_2O_3	2.67	5.00	2.53	1.77	10.07*	2.46	4.46	4.08	1.45
FeO	7.72	4.52	7.20	9.02	n.d.	7.21	8.24	5.64	17.19
MnO	0.18	0.14	0.19	0.19	n.d.	0.16	0.20	0.14	0.22
MgO	7.00	6.30	7.59	7.94	6.48	7.86	5.75	6.30	10.72
CaO	7.45	11.20	8.18	8.49	9.60	11.20	8.15	11.25	1.13
Na_2O	4.71	1.54	3.42	3.12	2.00	2.50	3.42	2.04	1.82
K_2O	0.02	0.17	0.11	0.07	0.28	0.35	0.07	0.17	0.05
P_2O_5	0.20	0.18	0.08	0.10	n.d.	0.08	0.11	0.22	0.11
CO_2	0.92	0.60	0.09	0.20	n.d.	0.10	0.00	0.48	0.10
H_2O+	2.40	1.47	2.82	3.80	3.60**	2.93	1.39	1.65	7.95
H_2O-	n.d.	n.d.	0.17	0.07	n.d.	0.07	n.d.	n.d.	0.10
S	n.d.	n.d.	n.d.	0.14	n.d.	n.d.	n.d.	n.d.	0.69
	99.12	99.33	99.68	99.97	100.03	99.92	99.36	99.65	100.23

Norms (C.I.P.W.)

	9	10	11	12	13	14	15	16	17
q	-	14.82	0.70	-		-	4.30	7.87	-
feld	59.29_{an33}	45.91_{an69}	55.85_{an47}	58.08_{an54}		54.65_{an58}	54.17_{an46}	52.26_{an65}	19.95_{an21}
ne	-	-	-	-		-	-	-	-
di	8.73	15.04	10.93	8.38		18.96	12.36	14.17	-
hy	12.46_{en54}	12.28_{en78}	24.92_{en57}	12.67_{en52}		11.85_{en58}	18.13_{en54}	15.62_{en65}	46.58_{en42}
ol	9.38_{fa55}	-	-	13.29_{fa58}		7.14_{fa51}	-	-	7.37_{fa67}
mt	3.87	7.24	3.66	2.56		3.56	6.46	5.91	2.10
hm	-	-	-	-		-	-	-	-
il	1.51	1.25	1.32	1.65		1.44	3.17	1.29	2.01
py	-	-	-	0.29		-	-	-	1.46
ap	0.46	0.41	0.18	0.23		0.18	0.25	0.50	0.25
cc	2.09	1.36	0.20	0.04		0.22	-	1.09	0.22
cor	-	-	-	-		-	-	-	14.36
salic	59.29	60.73	56.55	58.08		54.65	58.48	60.14	34.31
femic	38.53	37.61	14.24	39.15		43.38	40.39	38.60	60.01

*Total Fe as Fe_2O_3 **Loss on ignition n.d. - not determined

Table 3 (continued)

Rock Type & Location Key

1 - St. Patrick type metabasalt. Southeastern portion of the Whalesback area (see Fig. 1). 49° 35' 15" N, 55° 58' 50" W. Collected by V. S. Papezik. Analyzed by K. Ramlal, University of Manitoba.

2 - St. Patrick type metabasalt. Southeastern portion of the Whalesback area (see Fig. 1). 49° 35' 38" N, 55° 58' 33" W. Collected by V. S. Papezik. Analyzed by H. Dehn, University of Pittsburgh.

3 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig. 1). 49° 35' 20" N, 56° 01' 10" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

4 - St. Patrick type metabasalt. Northwest of Little Deer Pond (see Fig. 1). 49° 35' 05" N, 56° 01' 15" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

5 - St. Patrick type metabasalt. Northwest of Little Deer Pond (see Fig. 1). 49° 35' 10" N, 56° 01' 20" W. Collected by J. M. Fleming. Analyzed by H. Dehn, University of Pittsburgh.

6 - St. Patrick type metabasalt. Northwest of Little Deer Pond (see Fig. 1). 49° 35' 15" N, 56° 01' 25" W. Collected by J. M. Fleming. Analyzed by H. Dehn, University of Pittsburgh.

7 - St. Patrick type metabasalt. North of the road from Springdale to Little Bay, 500 yds. southwest of Davis Pond (see Fig. 2). 49° 32' 07" N, 56° 05' 12" W. Collected by V. S. Papezik. Analyzed by Durward Hall, General Minerals Co., Greensboro, North Carolina.

8 - Whalesback type metabasalt. About 1500 feet north of Little Deer Pond near the western Mine Licence boundary line (see Fig. 1). 49° 35' 02" N, 56° 01' 20" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

9 - Whalesback type metabasalt. About 600 feet north of Little Deer Pond (see Fig. 1). 49° 35' 00" N, 56° 01' 15" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

10 - Whalesback type metabasalt. South of Whalesback Pond (see Fig. 1). 49° 35' 40" N, 56° 00' 25" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

11 - Whalesback type metabasalt. About midway between Whalesback and Little Deer Ponds (see Fig. 1). 49° 35' 40" N, 56° 00' 40" W. Collected by J. M. Fleming. Analyzed by H. Dehn, University of Pittsburgh.

12 - Whalesback type metabasalt. Whalesback Mine, 975 level, about 30 feet north of shaft. Outer part of large pillow without chloritic "skin". Collected by V. S. Papezik. Analyzed by H. Dehn, University of Pittsburgh.

13 - Whalesback type metabasalt. About 100 feet east of a small lake (Vein Pond), ¾ mile north of Davis Pond (see Fig. 2). 49° 33' 44" N, 56° 04' 19" W. Collected by V. S. Papezik. Analyzed by Durward Hall, General Minerals Co., Greensboro, North Carolina.

14 - Gabbro. Small stock north of a small lake (Vein Pond), ¾ mile north of Davis Pond (see Fig. 2). 49° 33' 44" N, 56° 04' 25" W. Collected by V. S. Papezik. Analyzed by H. Dehn, University of Pittsburgh.

15 - Gabbro. Northwest of Little Deer Pond (see Fig. 1). 49° 35' 10" N, 56° 01' 20" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

16 - Gabbro. North of Little Deer Pond (see Fig. 1). 49° 35' 35" N, 56° 00' 35" W. Collected by J. M. Fleming. Analyzed by K. Ramlal, University of Manitoba.

17 - Chlorite rock. Whalesback Mine, 425 level, 445-2 X-cut. Central part of the ore zone. Collected by V. S. Papezik. Analyzed by H. Dehn, University of Pittsburgh.

Partial Analyses of Rocks from

the Whalesback Area

	18	19	20	21	22
SiO_2	52.4	52.5	57.9	51.9	56.2
TiO_2	1.40	1.27	1.25	1.30	1.39
CaO	5.60	4.99	3.64	6.28	4.54
Na_2O	4.37	5.30	4.82	3.30	6.05
K_2O	0.47	0.35	0.13	0.10	0.45
	23	**24**	**25**	**26**	**27**
SiO_2	51.1	46.1	52.5	49.5	52.4
TiO_2	1.32	0.90	0.92	1.05	1.15
CaO	6.05	12.38	7.68	5.38	6.78
Na_2O	4.60	1.85	4.42	3.65	2.47
K_2O	0.10	0.08	0.16	0.13	0.13

18 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig. 1). 49° 35' 20" N, 56° 01' 05" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

19 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig. 1). 49° 35' 15" N, 56° 01' 10" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

20 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig. 1). 49° 35' 15" N, 56° 01' 25" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

21 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig 1). 49° 35' 10" N, 56° 01' 25" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

22 - St. Patrick type metabasalt. North of Little Deer Pond (see Fig. 1). 49° 35' 10" N, 56° 01' 30" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

23 - St. Patrick type metabasalt. Near the southern corner of the Whalesback area about 700 feet east of the Whalesback access road (see Fig. 1). 49° 34' 25" N, 56° 00' 55" W. Collected by Sunhil Gandhi. Analyzed by E. Burke, Nfld. Mineral Resources Division.

24 - Whalesback type metabasalt. Near the southwestern end of Whalesback Pond (see Fig. 1). 49° 35' 40" N, 56° 00' 50" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

25 - Whalesback type metabasalt. South of Whalesback Pond (see Fig. 1). 49° 35' 35" N, 56° 00' 45" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

26 - Whalesback type metabasalt. South of the Little Deer ore zone, near the shore of Little Deer Pond (see Fig. 1). 49° 35' 10" N, 56° 01' 05" W. Collected by J. M. Fleming. Analyzed by E. Burke, Nfld. Mineral Resources Division.

27 - Whalesback type metabasalt. Near the south corner of the Whalesback area, about 400 feet east of the Whalesback access road (see Fig. 1). 49° 34' 35" N, 56° 01' 00" W. Collected by Sunhil Gandhi. Analyzed by E. Burke, Nfld. Mineral Resources Division.

for SiO_2, TiO_2, CaO, Na_2O, and K_2O only. The results are tabulated in Table 4. The alkalies were determined by flame photometric methods, CaO by titration with permanganate, and TiO_2 and SiO_2 colorimetrically (molybdenum blue).

Chemical Characteristics of the Whalesback and St. Patrick Volcanics

The distribution of most of the major oxides in the two types of flow rock is illustrated in Figures 4, 5, and 6. The Whalesback and St. Patrick rocks differ most distinctly in their contents of TiO_2, FeO, MgO, CaO (Fig. 4) and total iron (Fig. 5). TiO_2 is consistently below 1% in the Whalesback volcanics, averaging 0.78%, but in the St. Patrick volcanics TiO_2 ranges between 1% and 1.5%, averaging 1.13% (see Table 7-A, B & C for average compositions). FeO is generally higher in the St. Patrick volcanics than in the Whalesback type; Fe_2O_3 shows a similar but more erratic distribution. Total iron, however, is distinctly greater in the St. Patrick volcanics and decreases with increasing silica content within each flow type along almost linear trends. MgO shows a similar but less marked tendency to decrease with increasing silica content within each flow type. CaO is more erratic but tends to be less than 6.5% in the St. Patrick rocks and greater in the Whalesback rocks.

The total alkalies show a general increase with increasing silica content (see Fig. 7) although the distribution is quite erratic. Potash is consistently below 0.2%; the few higher values, up to 0.72%

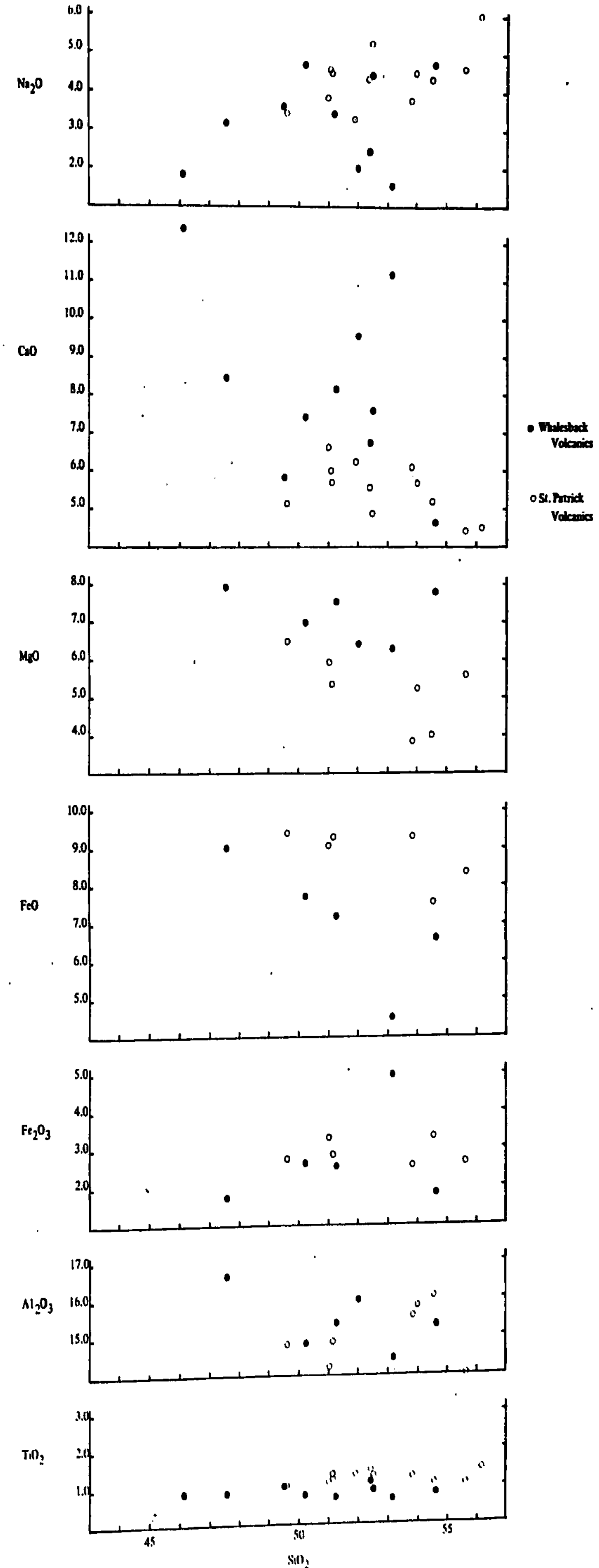

Figure 5: Distribution of the major oxides in the Whalesback and St. Patrick Volcanics.

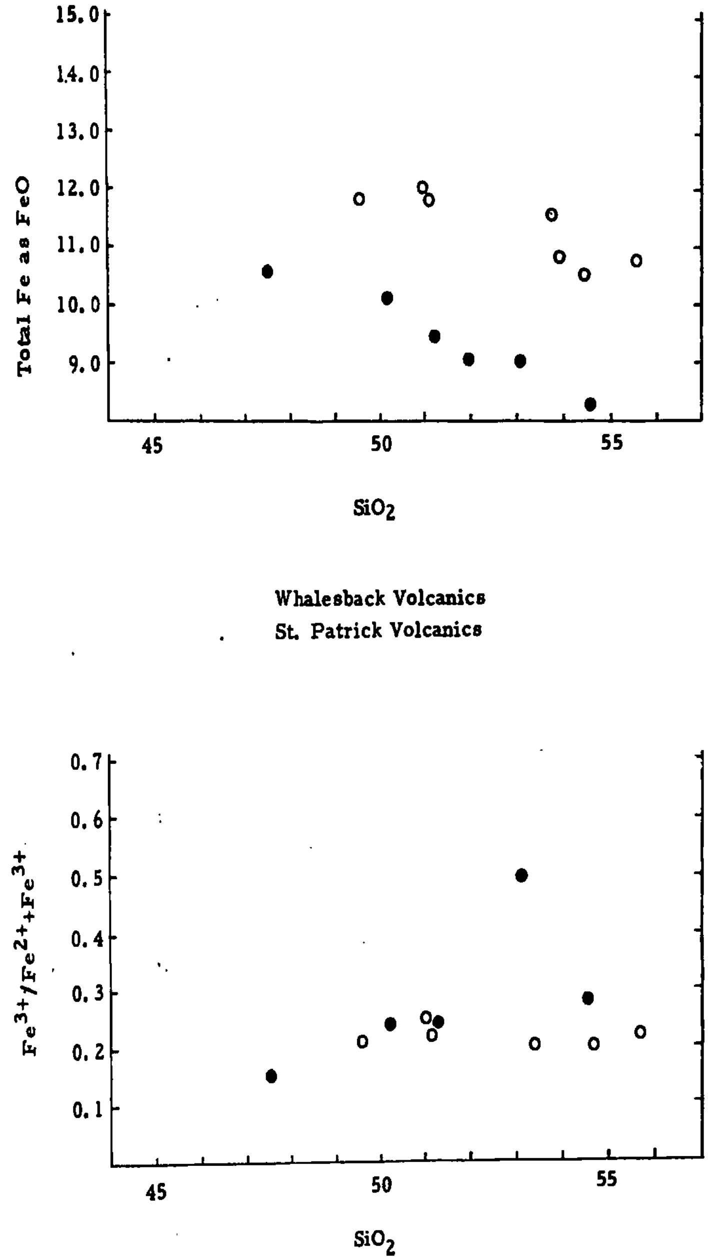

Figure 5 - A(top): Distribution of total iron in the Whalesback and St. Patrick Volcanics.

B(bottom): Variation of oxidation state ($Fe^{3+}/Fe^{2+}+Fe^{3+}$) in the Whalesback and St. Patrick Volcanics.

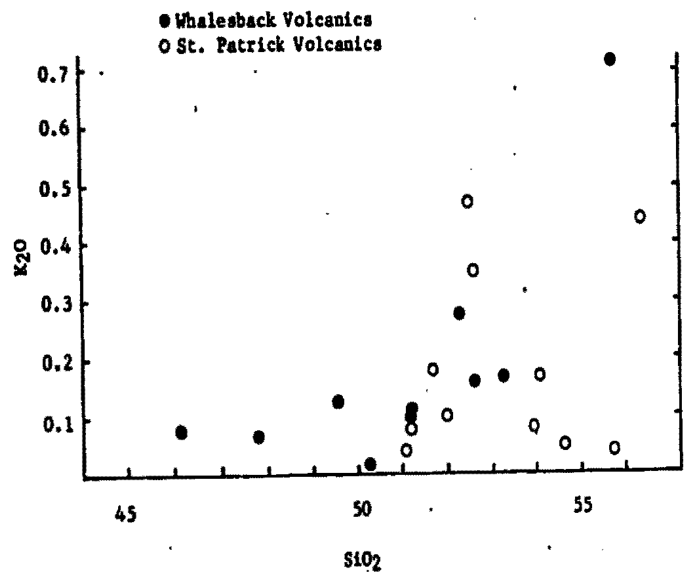

Figure 6. Distribution of K_2O in the Whalesback & St. Patrick Volcanics.

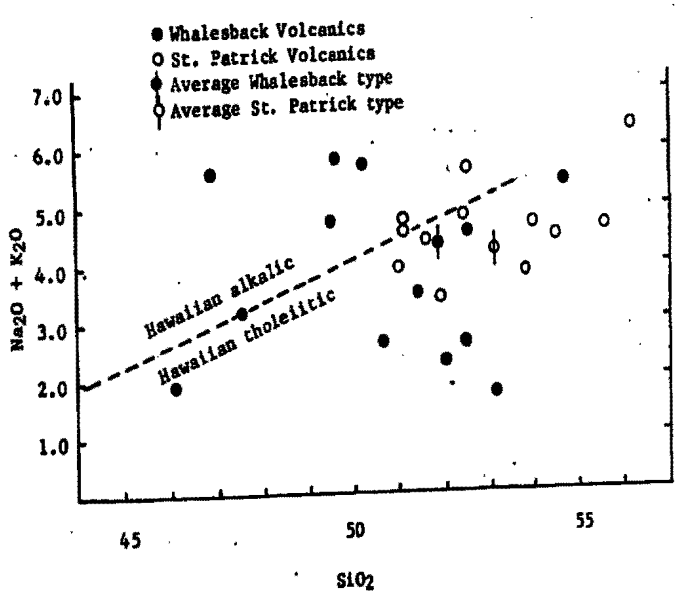

Figure 7. Alkalies vs. SiO_2 in the Whalesback and St. Patrick Volcanics. Hawaiian alkalic-tholeiitic boundary after MacDonald & Katsura(1964).

(Analysis No. 8), were obtained from specimens showing a higher degree of alteration than normal in the area. One specimen, No. 3, was reported to contain 2.40% K_2O, an abnormally high value which is as yet unexplained. This is not plotted on Figure 6. Soda (see Fig. 4) accounts for most of random distribution in Figure 7; the Whalesback-type rocks show the most erratic values ranging from 1.54% to 4.72% and averaging 4.04% (Table 7, A). The St. Patrick rocks show a smaller range of soda values from 3.30 to 5.30, averaging 4.15%.

The variations between the Whalesback and St. Patrick volcanics are illustrated by Figures 8 and 9, ternary diagrams showing $CaO-K_2O-Na_2O$ and $MgO-FeO-Na_2O+K_2O$ distributions, respectively. Disregarding the two abnormally high values of potash (Analyses 3 & 8), the St. Patrick volcanics are generally enriched in soda in comparison with the Whalesback lavas (see Fig. 8), but the whole sequence is consistently low in potash. The St. Patrick rocks, however, differ most from those of the Whalesback type in their relative enrichment in iron compared to magnesium (see Fig. 9). The MFA diagram also illustrates a trend within each flow type toward enrichment in soda.

Three analyses were obtained of gabbroic rocks; two (Nos. 14 & 16, Table 3) represent the gabbros found intruding the Whalesback lavas and one (No. 15, Table 3) is of gabbroic rock intrusive into the St. Patrick volcanics. On the MFA diagram (Fig. 9) the gabbro analyses plot with their respective host rocks. This confirms

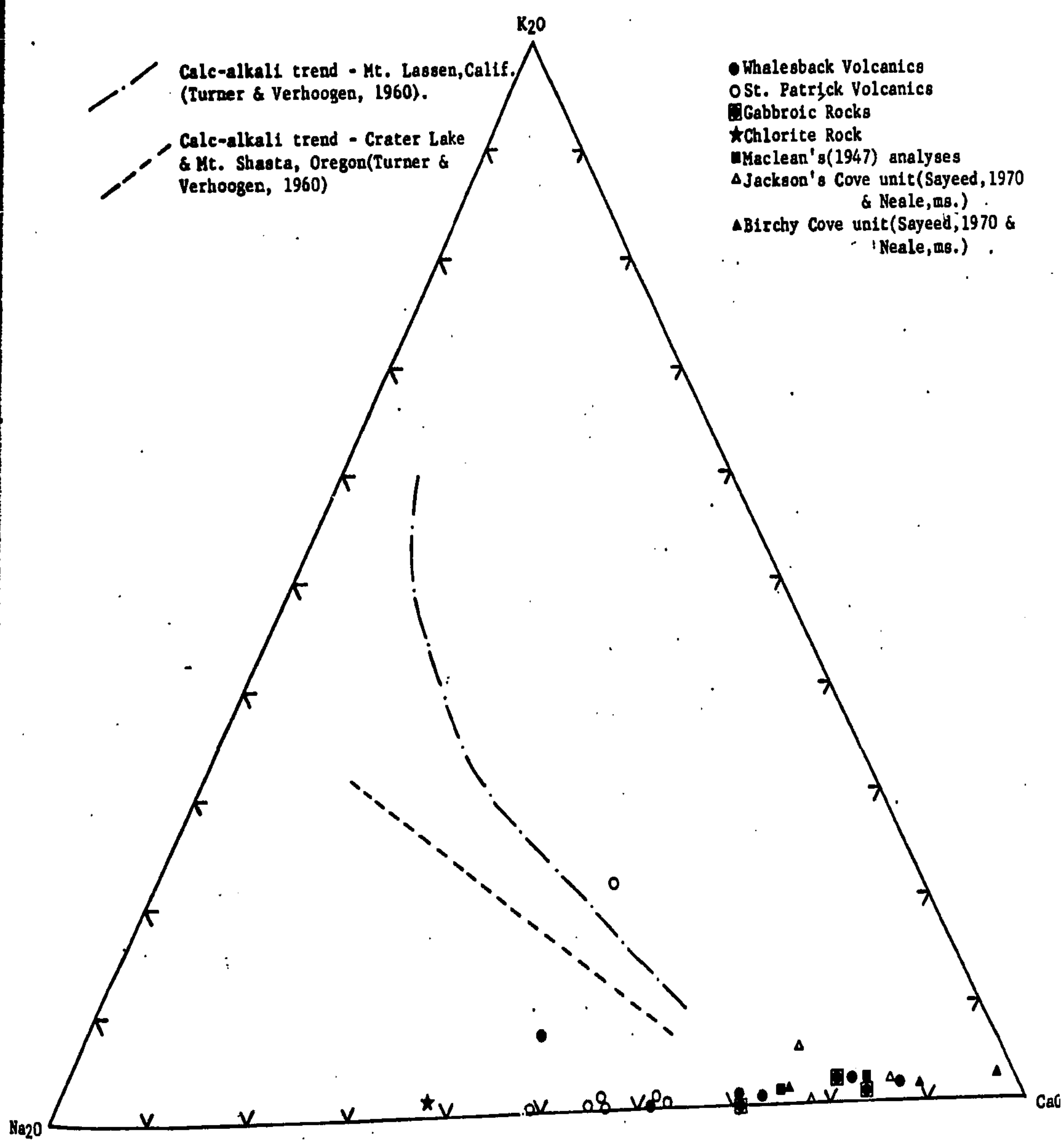

Figure 8. Distribution of K_2O, Na_2O & CaO in the Lush's Bight Group compared with calc-alkali trends at Mt. Lassen, Crater Lake & Mt. Shasta.

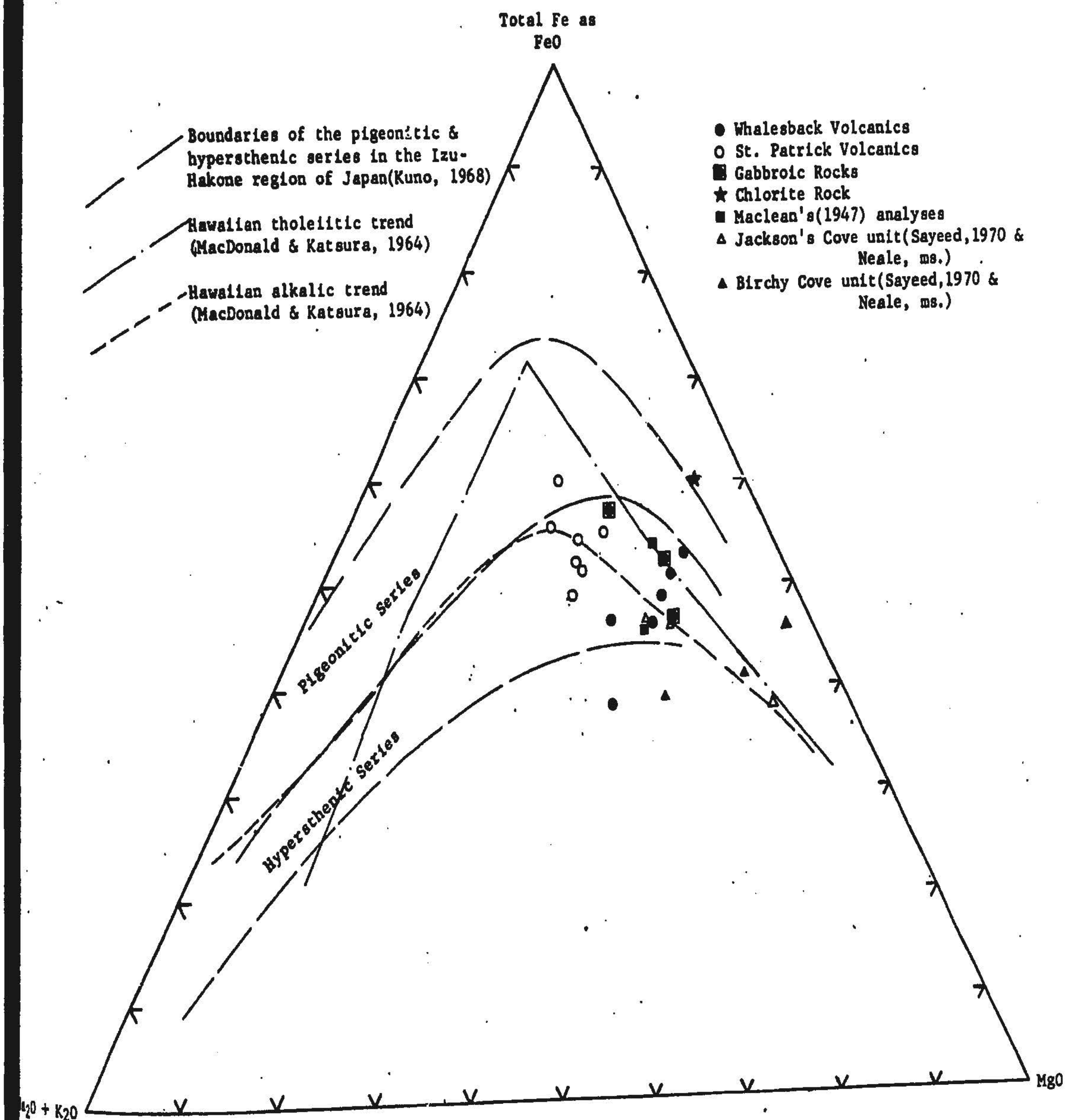

Figure 9. MFA diagram showing the Lush's Bight Group rocks in relation to the Hawaiian lavas and those of the Izu-Hakone region of Japan.

the interpretation that the gabbros are of two main types, similar to the Whalesback and St. Patrick types of flow rock, which represent feeders of the volcanic pile.

Petrologic Interpretation

Introduction

The detailed mapping in the Whalesback area has shown that the Whalesback and St. Patrick volcanics can be consistently recognized and differentiated in the field. Similar rocks occur for considerable distances along strike to the northeast and southwest, as indicated by analyses MCL-2, Table 6 (Maclean, 1947) and No. 13, Table 3, both Whalesback types, and by analysis No. 2, Table 3, of the St. Patrick type (V.S. Papezik, personal communication). An additional analyzed specimen, collected by Neale (ms.) northwest of the Whalesback area (Table 6, NA-3158), is similar to the Whalesback volcanics. Whether the distinction between the two types might have any stratigraphical or structural significance, however, depends on whether their main differences are primary or merely the results of metasomatism. The effects of metasomatism, then, must be identified and evaluated.

Metasomatic Effects

With a few exceptions, the analyses of both the Whalesback and St. Patrick volcanics pass through the 'screen' for basaltic rocks developed by Manson (1967) (see Table 5). This numerical screen was

Table 5

Comparison of the Whalesback & St. Patrick Volcanics With Manson's (1967) Chemical Screen for Basaltic Rocks

	Screen (%)	Whalesback Volcanics (%)	St. Patrick Volcanics (%)
SiO_2	<56.00	47.52 - 54.65	49.60 - 55.65
TiO_2	<5.50	0.66 - 0.87	1.02 - 1.25
Al_2O_3	10.50 - 22.00	14.40 - 16.67	14.00 - 16.08
Fe_2O_3	<6.00	1.77 - 5.00	2.56 - 3.33
FeO	2.50 - 15.00	4.52 - 9.02	7.53 - 9.40
MnO	<1.00	0.10 - 0.19	0.16 - 0.20
MgO(FeO < 10%)	>3.00	5.28 - 7.94	3.85 - 6.50
CaO	5.00 - 15.00	4.70 - 11.20	4.40 - 6.64
Na_2O	<5.50	1.54 - 4.72	3.47 - 4.62
P_2O_5	<1.50	0.08 - 0.20	0.11 - 0.22
total H_2O	<4.00	2.40 - 3.87	2.44 - 3.63
CO_2	<0.50	0.00 - 0.92	0.02 - 1.53
Analysis total	99.00 -101.00	99.04 -100.03	99.11 - 99.76
q	<12.50	0.00 - 14.82	0.00 - 8.23
or(ne=o)	<15.00	0.11 - 4.25	0.23 - 0.47
cc	0.00	0.00 - 2.09	0.04 - 3.47
wo	0.00	1.62 - 7.81	0.00 - 2.68
ol(ne=o)	<15.00	0.00 - 13.29	0.00 - 9.38
hm	0.00	0.00	0.00
CI*(Fe <10%)	35.00 - 70.00	30.97 - 49.41	24.26 - 30.52
An(Fe <10%)	35.00 - 80.00	29.00 - 69.00	29.00 - 43.00

*Crystallization Index (Poldervaart & Parker, 1964) devised as a method of selecting analyses which conform to the accepted mineralogical definition of basalt; it places limits on both chemical and normative values. At least some of the effects of metasomatism are evident where the Whalesback and St. Patrick analyses fail to conform to the screen's limits, i.e., where the rocks differ from 'normal', unaltered basalts.

Chemically, the analyses deviate from the screen's limits only in their contents of CaO and CO_2. CaO is outside the screen's limits in only two of the analyses (Nos. 4 & 8, Table 3) where it falls below the screen's minimum value. CO_2, however, exceeds the screen's limits in most of the analyses and high CO_2 accompanies the higher values of CaO. This is reflected in the norm by high calcite values. The mobility of calcium and CO_2 is evident from the numerous amygdules and veinlets of calcite and epidote. There does not appear to have been any metasomatic addition or subtraction of calcium although CO_2 might have been added; rather, metasomatism has probably only effected a redistribution of these components.

The normative plagioclase in both the Whalesback and St. Patrick volcanics is often more sodic than is usual in basaltic rocks, as indicated by the screen. This can be accounted for by metasomatic addition of soda. There is no direct evidence for soda metasomatism but it is strongly suggested by the MFA diagram (Fig. 9). The trend from Whalesback to St. Patrick-type rocks, involving mainly enrichment in iron at the expense of magnesium and some enrichment in alkalies, is a common feature of basaltic rock series. However, Figure 9 shows that a second trend - a selective alkali enrichment within each rock type - is superimposed on the first. This second trend is best explained by the metasomatic addition of soda. Also, the very irregular variation of Na_2O with SiO_2 (Fig. 4) is more readily explained as a metasomatic than a primary feature. Soda metasomatism can also account for the presence of wollastonite in the norms. The excessive amounts of soda require the use of so much Al_2O_3 in forming albite that not enough Al_2O_3 is left to accommodate all the CaO in anorthite. The excess CaO then forms normative wollastonite.

Since free silica is frequently encountered in the rocks as amygdules and veinlets, silicification of the lavas might be expected to have taken place. This may have occurred to a small degree locally but the analyses indicate that silicification has not reached major proportions. The range of silica contents in the analyses is within that normally encountered in basaltic rocks. The St. Patrick lavas are consistently higher in silica than the Whalesback volcanics, but only by amounts which would normally be expected to accompany their enrichment in iron and alkalies in the process of magmatic differentiation.

Another expected effect of alteration is oxidation of iron which increases the amount of normative hypersthene (Coombs, 1963). Oxidation of the lavas has undoubtedly taken place but the variation of oxidation state with SiO_2 (Fig. 5b) indicates that the effects have been rather consistent throughout the sequence with some local abnormal effects suggested by the scattering of a few of the analyses. None of the analyses, however, contains more than 5% Fe_2O_3, the figure used by Coombs (1963) in separating highly oxidized basalts from normal basalts.

The MFA diagram (Fig. 9) shows that the two rock types differ most in their relative amounts of iron; in addition, the St. Patrick volcanics are relatively enriched in soda. This corresponds approximately to the differentiation trend of basaltic rocks which developed by fractionation in the crust, suggesting that the main differences between the two flow types are primary. The MFA diagram, however, represents only three components. To test further the significance of the differences between the two flow types the analyses were plotted according to the method of Manson (1967). By factor analysis of 1996 analyses of basaltic rocks Manson reduced the twelve major oxides to four factor coefficients which can be represented as end members on a tetrahedron. Any new analysis can be plotted on this diagram by first standardizing the analysis by dividing each oxide by the square root of the sum of squares of all 12 oxides. The four end members are then obtained by summing the products of the standardized oxides and the four factor measurements for each oxide tabulated by Manson (1967). The Whalesback and St. Patrick analyses have been plotted on the 1-2-3 face of the tetrahedron (Figure 10), the face which displays the maximum variation. Analyses of the two flow types plot in two

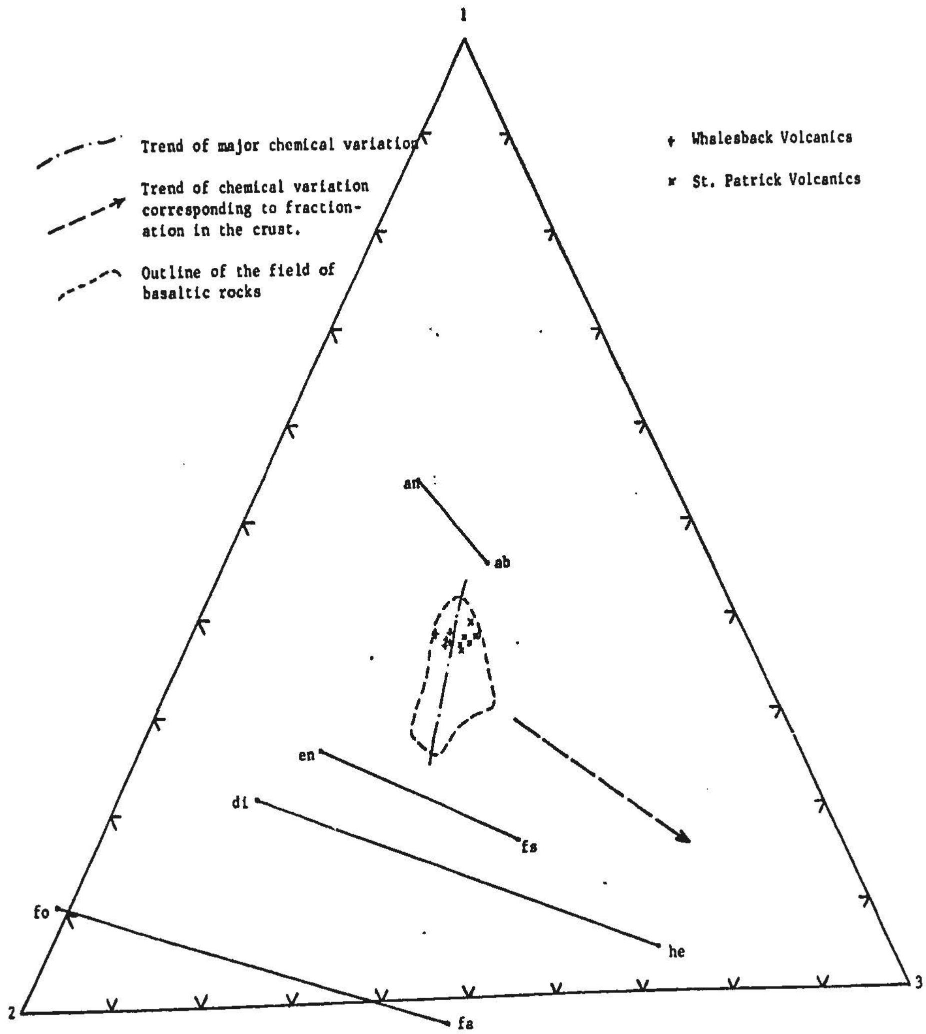

Figure 10. Whalesback and St. Patrick volcanics plotted on the 1-2-3 face of the factor coefficient tetrahedron of Manson(1967). For explantion see text.

distinct groups indicating that the Whalesback and St. Patrick volcanics are significantly different in chemical composition. Such differences are unlikely to have been brought about by secondary alteration alone.

To sum up, the St. Patrick volcanics appear to have been enriched in iron and somewhat enriched in soda relative to the Whalesback-type flows at the time of extrusion. Subsequent metasomatism led to an enrichment of each flow type in soda, some redistribution of calcium and CO_2, and oxidation of iron.

Primary Nature of the Lavas

Both the Whalesback and St. Patrick volcanics are basalts according to Manson's (1967) definition. Manson's chemical screen, however, embraces a rather broader range of rocks than many workers would term 'basalt'. Thus, while the Whalesback volcanics are clearly 'basalts', some authors (e.g., Williams et al., 1954; Johannsen, 1937) would call the St. Patrick volcanics 'andesites' because of their higher silica content (average 53.13% SiO_2) and highly sodic normative plagioclase (average An_{38}). Most andesites, however, are more silicic and have more highly sodic normative plagioclase than the St. Patrick rocks. For instance, the average Cenozoic andesite (Chayes, 1969) contains 57.17% SiO_2 and normative plagioclase averaging 27.30% An. The application of the term 'andesite' to the St. Patrick volcanics, then, is hardly justified. The term 'basaltic andesite', however, has been widely applied to rocks of basaltic composition but which have some transitional characteristics (Coats, 1968); it is in this sense that the term can be applied here to the St. Patrick volcanics.

In a preliminary report on this study (Papezik and Fleming, 1967) it was suggested that, whereas the Whalesback volcanics are tholeiitic, the St. Patrick volcanics are 'spilites'. A spilitic character was suggested by an apparent appreciable enrichment in soda in the St. Patrick rocks in comparison with normal Whalesback rocks (averaged in Table 6, B) and by the similarity between the chemical composition of the St. Patrick rocks and "average spilite" (Table 7, D); the regional association with cherts and ultrabasic rocks (see Chap. 2) also is typical of spilites. At that time, specimens 8 and 9, Table 3, which are mineralogically similar to the Whalesback volcanics but chemically show similarities to both flow types, were excluded in computing an average composition for the Whalesback volcanics. They do, however, group with the Whalesback volcanics in both the MFA and factor analysis diagrams, Figures 9 and 10. They must, therefore, be considered as variations of the Whalesback rocks and are included in the average composition in Table 7, A. Both flow types, then, are enriched in soda as compared with normal tholeiitic basalts but this has now been shown to be a probable metasomatic effect. Amstutz (1968) has since pointed out that the available chemical data on spilites have been greatly influenced by sampling errors and thus cannot be used to define the term. The term 'spilite' is, then, so ill-defined and controversial that little would be achieved in applying it to any of the rocks of the Whalesback area.

The norms of both the Whalesback and St. Patrick volcanics contain relatively high amounts of hypersthene, a widely accepted indication of tholeiitic character (Poldervaart, 1964). The amount of normative hypersthene can be increased by oxidation but the rocks of the Whalesback area are not highly oxidized, certainly not to an extent that could account for the presence of most or all of the hypersthene in the norms. The distribution of alkalies vs. silica is also useful in distinguishing between tholeiitic and alkalic rocks (MacDonald & Katsura, 1964), and the tholeiitic-alkalic boundary for the Hawaiian rocks is included in Figure 7 for comparison. In spite of the random distribution of soda, most specimens of both flow types lie within the tholeiitic field. In addition, both the average Whalesback and average St. Patrick compositions (Table 7) fall below the alkalic-tholeiitic boundary.

The Whalesback and St. Patrick volcanics are, then, basalts and basaltic andesites, respectively, both of tholeiitic character. Their close association in the field and common deficiency in potash indicates that they are closely related. On the MFA diagram (Fig. 9) they fall on a trend which suggests that they are parts of a differentiation series. This is also suggested by the factor analysis diagram (Fig.10) where the line of variation from Whalesback-type to St. Patrick-type rocks is roughly parallel to the trend corresponding to fractionation in the crust.

Significance of the Primary Differences between the Whalesback and St. Patrick Volcanics

The suggestion that the two lava types of the Whalesback area are the products of differentiation of basaltic magma also implies a possible stratigraphic relationship of the types distinguished. The St. Patrick-type flows, being the later differentiates, should be higher in the stratigraphic sequence than the Whalesback lavas. This interpretation is supported by the preponderance of gabbroic intrusive rocks, interpreted to be feeders of the volcanic pile, in the Whalesback volcanics and their relative scarcity in the St. Patrick lavas. Within the Whalesback area the lack of structural data severely limits the possible usefulness of this stratigraphic relationship in working out the structure of the area. As has been already pointed out, however, the Whalesback and St. Patrick volcanics are known to occur for considerable distances along strike to the northeast and southwest of the Whalesback area. In view of their possible stratigraphic significance, careful mapping of the two rock types over a larger area would be a valuable aid in understanding the overall structure of this part of the Lush's Bight Group.

Comparison with Other Parts of the Lush's Bight Group

Sayeed (1970), in the course of mapping in the area of the Colchester plutons on the western side of the Springdale Peninsula, distinguished two types of pillowed basalts which he called the Jackson's Cove and Birchy Cove units. The two units were distinguished mainly on the basis of size and shape of pillows and the presence of variolitic texture in the Birchy Cove unit. The Birchy Cove rocks were also found to be less altered. Mineralogically, both the Jackson's Cove and Birchy Cove units are similar to the flow rocks in the Whalesback area.

Three analyses of each unit have been made (Sayeed, 1970, Neale, ms.) and are reproduced in Table 6. One of these, S-332, is the average of three separate analyses of the top, central, and bottom portions of one pillow which showed insignificant variations. The analyses have been plotted on the K_2O - Na_2O - CaO diagram (Fig. 8) and on the MFA diagram (Fig. 9). The Jackson's Cove unit is, in general, similar to the Whalesback type although one analysis is more basic, plotting more toward the lime and magnesia corners of the diagrams, respectively. The Birchy Cove rocks have lower Fe/Mg ratios and are more calcic than the Whalesback type rocks. These also exhibit a variation toward the alkali corner of the MFA diagram similar to that in the Whalesback and St. Patrick rocks. The Jackson's Cove and Birchy Cove rocks are lower in titania than the flows in the Whalesback area but are similar to the latter in being generally potash deficient.

The limited data available suggest that the Jackson's Cove and Birchy Cove rocks are part of the same volcanic series as the Whalesback and St. Patrick lavas and are in part more basic than the Whalesback volcanics.

One analysis of metabasalt from the Western Arm section of the Lush's Bight Group has been reported by Maclean (1947) (see Table 6, MCL-1). It is, in general, similar to the Whalesback volcanics but contains more TiO_2 and less Na_2O.

Table 6

Analyses of Lush's Bight Group Rocks

Outside the Whalesback Area

	MCL-1	MCL-2	S-35	NA-3153	NA-3152	S-333	NA-3155	S-332[1]	NA-3158
SiO_2	46.92	48.82	58.3	50.3	47.1	48.7	51.6	50.1	46.4
TiO_2	1.72	0.85	-	0.80	1.5	0.38	0.33	0.29	0.83
Al_2O_3	16.32	15.67	8.1	15.5	16.4	13.8	17.0	13.23	14.3
Fe_2O_3	2.85	1.79	7.59*	2.4	3.0	10.30*	2.2	9.23	3.4
FeO	8.26	7.57	-	6.25	7.67	-	5.16	-	6.60
MnO	0.18	0.18	0.12	0.15	0.17	-	0.15	0.16	0.14
MgO	6.62	7.41	9.92	6.5	8.6	10.54	7.8	9.59	7.2
CaO	12.40	10.46	8.69	11.0	9.1	12.08	9.7	12.47	12.2
Na_2O	2.32	3.38	1.15	3.1	2.6	0.21	3.1	1.34	1.4
K_2O	0.23	0.20	0.27	0.04	0.54	0.35	0.18	0.21	0.36
P_2O_5	0.18	0.05	-	0.03	0.16	-	0.02	-	0.02
CO_2	0.03	1.10	-	0.43	0.48	-	0.24	-	2.9
H_2O+	1.92	2.65	4.80**	2.5**	3.3**	3.59**	3.2	2.91**	3.5**
H_2O-	0.08	0.03	-	-	-	-	-	-	-
S	-	0.07	-	-	-	-	-	-	-
	100.03	100.20	98.9	99.0	100.6	99.9	100.7	99.5	99.3

* Total Fe as Fe_2O_3 ** Loss on ignition [1] Average of 3 analyses from one pillow

MCL-1 - Slightly altered basalt from the Western Arm Section of the Lush's Bight Group. North shore of Hennessey Island, Three Arms, Green Bay. (Maclean, 1947).

MCL-2 - Strongly altered basalt (Little Bay Head Section). Morris Cove, 2500 feet southwest of North Bill, Little Bay Head, Green Bay. (Maclean, 1947).

S-35 - Metabasalt from the Jackson's Cove Unit of the Lush's Bight Group. Western side of the Springdale Peninsula near Saunder's Brook. (Sayeed, 1970).

NA-3153 - Metabasalt from the Jackson's Cove Unit of the Lush's Bight Group. Western side of the Springdale Peninsula, 6500 feet at S 35° E from Jackson Cove Road bridge over South Brook. (Neale, M.S.).

NA-3152 - Metabasalt from the Jackson's Cove Unit of the Lush's Bight Group. Western side of the Springdale Peninsula, 4200 feet south of southeast tip of Western Arm. (Neale, M.S.).

S-333 - Metabasalt from the Birchy Cove Unit of the Lush's Bight Group. Western side of the Springdale Peninsula, Birchy Cove, Colchester area. (Sayeed, 1970).

NA-3155 - Metabasalt from the Birchy Cove Unit of the Lush's Bight Group. Western side of the Springdale Peninsula, tip of promontory in middle of Birchy Cove. (Neale, M.S.).

S-332 - Average of three analyses from the top, center and bottom portions of one pillow in the Birchy Cove Unit of the Lush's Bight Group, reported by Sayeed (1970). Western side of the Springdale Peninsula, Birchy Cove, Colchester area.

NA-3158 - Metabasalt apparently of the Whalesback type. Specimen from 6000 feet at N 60° W from southwest tip of Whalesback Pond. (Neale, M.S.).

Table 7

Average & Comparative Compositions

	A	B	C	D	E	F
SiO_2	51.89	50.83	53.13	49.73	51.1	49.34
TiO_2	0.78	0.75	1.13	1.55	1.6	1.49
Al_2O_3	15.23	15.54	15.07	15.92	16.2	17.04
Fe_2O_3	2.55	3.11	2.94	3.79	3.1	1.99
FeO	7.09	6.94	8.92	6.48	7.6	6.82
MnO	0.15	0.17	0.17	-	0.17	0.17
MgO	7.38	7.30	5.27	5.00	6.2	7.19
CaO	7.16	9.33	5.60	6.44	9.9	11.12
Na_2O	4.04	2.70	4.15	4.30	2.5	2.73
K_2O	0.29	0.12	0.06*	1.24	0.7	0.16
P_2O_5	0.16	0.12	0.18	0.39	0.22	0.16
CO_2	0.41	0.30	0.57	2.20	-	-
H_2O (total)	2.26	2.79	2.81	2.96	0.7**	1.27

*Anomalously high value of 2.40% K_2O in Analysis No. 3 excluded

**H_2O+

A - Average Whalesback type metabasalt. Average of analyses 8-12 (Table 3) inclusive.

B - Average of selected analyses of Whalesback type metabasalts, analyses 10, 11 & 12 (Table 3) only.

C - Average St. Patrick type metabasalt. Average of analyses 1-6 (Table 3) inclusive.

D - Average spilite composition. Average of 105 analyses calculated by V.S. Papezik (Papezik & Felming, 1967).

E - Average theleiitic basalt (Manson, 1967, Table VI, No. 17).

F - Average oceanic theleiitic basalt (Engel et al., 1965).

Origin of the Lavas

On the basis of only twenty analyses from restricted areas, any comments concerning the origin of the lavas can only be conjecture. Nevertheless, some relevant speculations can be mentioned.

Probably the most characteristic chemical feature of the Whalesback and St. Patrick volcanics is their consistent deficiency in K_2O as compared with the average tholeiite (Table 7, E). Low K_2O is also a feature of the Jackson's Cove and Birchy Cove units (Sayeed, 1970; Neale, ms.) and Maclean's (1947) analyses (see Table 6). In this respect all these rocks resemble oceanic tholeiites (Table 7, F) (Engel et al., 1964; Engel et al., 1965; Kay et al., 1970).

Indirect support for an analogy with ocean flow basalts is found in the fact that pillowed metabasalts and serpentinized ultrabasic rocks have been found to occur along modern oceanic ridges, e.g., Aumento (1970), Aumento & Loncarevic (1969), Cann (1969). The study by Cann (1969) on metabasalts from the Carlsberg ridge is particularly relevant. He was able to show that the alteration of the basalts involved the loss of significant amounts of CaO and Al_2O_3, and possible significant gains in SiO_2, total Fe, and Na_2O. At least some of these processes have been shown to have affected the rocks of the Whalesback area.

A correlation with oceanic tholeiites is consistent with the model for the tectonic development of Northeastern Newfoundland developed by Dewey (1969) and Bird and Dewey (1970), where the Lush's Bight

Group is envisaged to be former oceanic crust.

The trend of the Whalesback and St. Patrick volcanics toward only moderate iron-enrichment (see Fig. 9), as compared with most tholeiitic rocks, e.g., the Hawaiian tholeiites (MacDonald and Katsura, 1964), might be considered to be a contradiction of the correlation with oceanic tholeiites. Moderate iron-enrichment is considered to be characteristic of calc-alkaline rocks (Kuno, 1968; Best, 1969) and most of the Whalesback and St. Patrick analyses fall within Kuno's hypersthenic (calc-alkaline) field (Fig. 9). Calc-alkaline rocks, however, typically exhibit a trend toward potash enrichment (Turner & Verhoogen, 1960; Best, 1969), a feature notably absent from the Whalesback area rocks. The Whalesback-St. Patrick trend toward moderate iron enrichment may be only apparent, largely due to the restricted chemical range of the analyses. It may also have been affected by sodium metasomatism.

The correlation of the Lush's Bight Group rocks with oceanic tholeiites is, at best, only tentative at this stage. The most characteristic feature of oceanic tholeiites is their distinctive trace element distribution (Kay et al., 1970). The need for more major element analyses over a wider area and a greater range of rock types has already been pointed out but trace element data, especially, are needed before the correlation can be confirmed.

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View southward from the ridge northwest of Little Deer Pond; typical of the topography of the Springdale Peninsula.

PLATE I

PLATE II

View southwestward over Little Deer Pond. Whalesback access road is visible in left background.

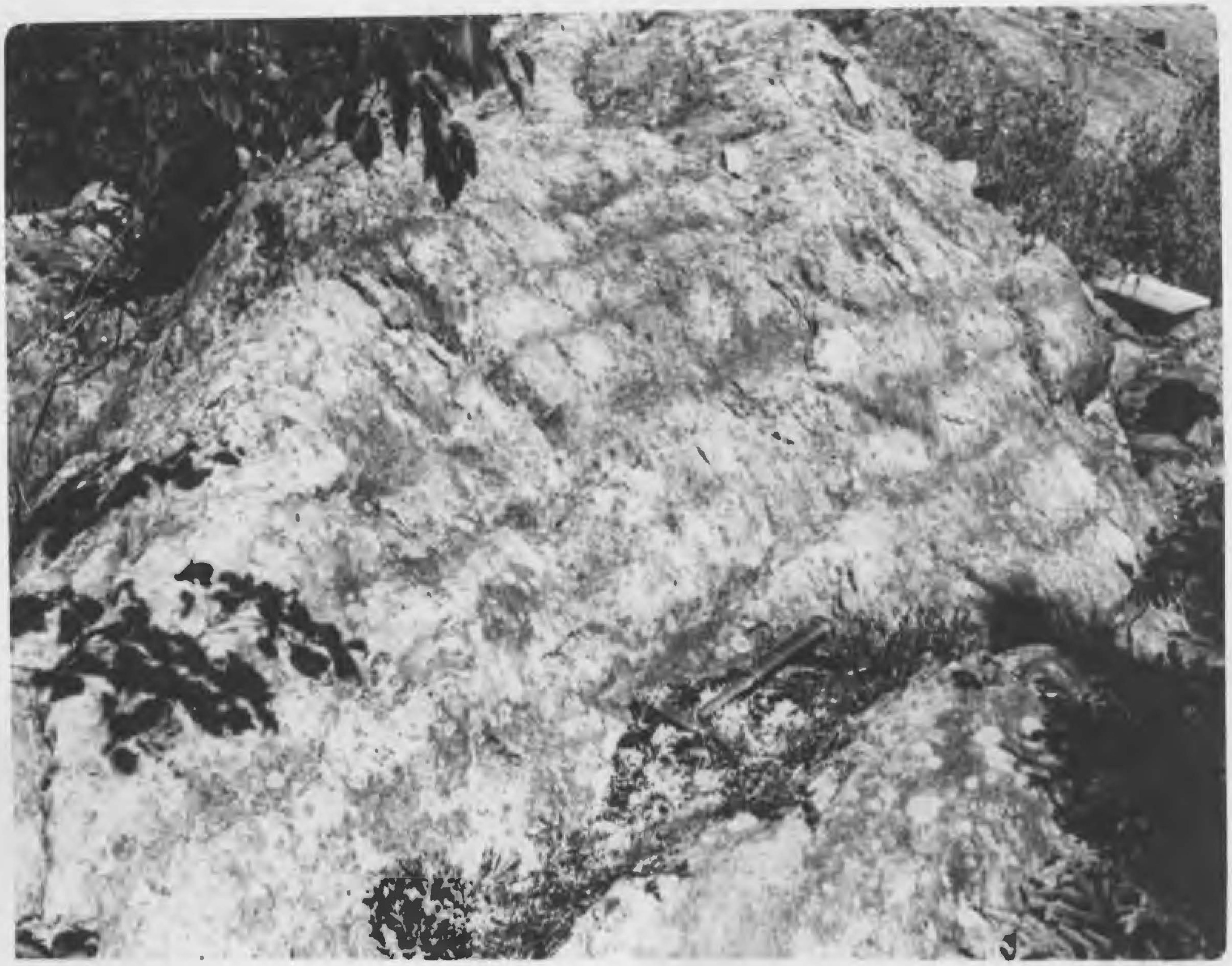
PLATE III

Whalesback Pond following drainage of part of the pond to provide sites for mine buildings.

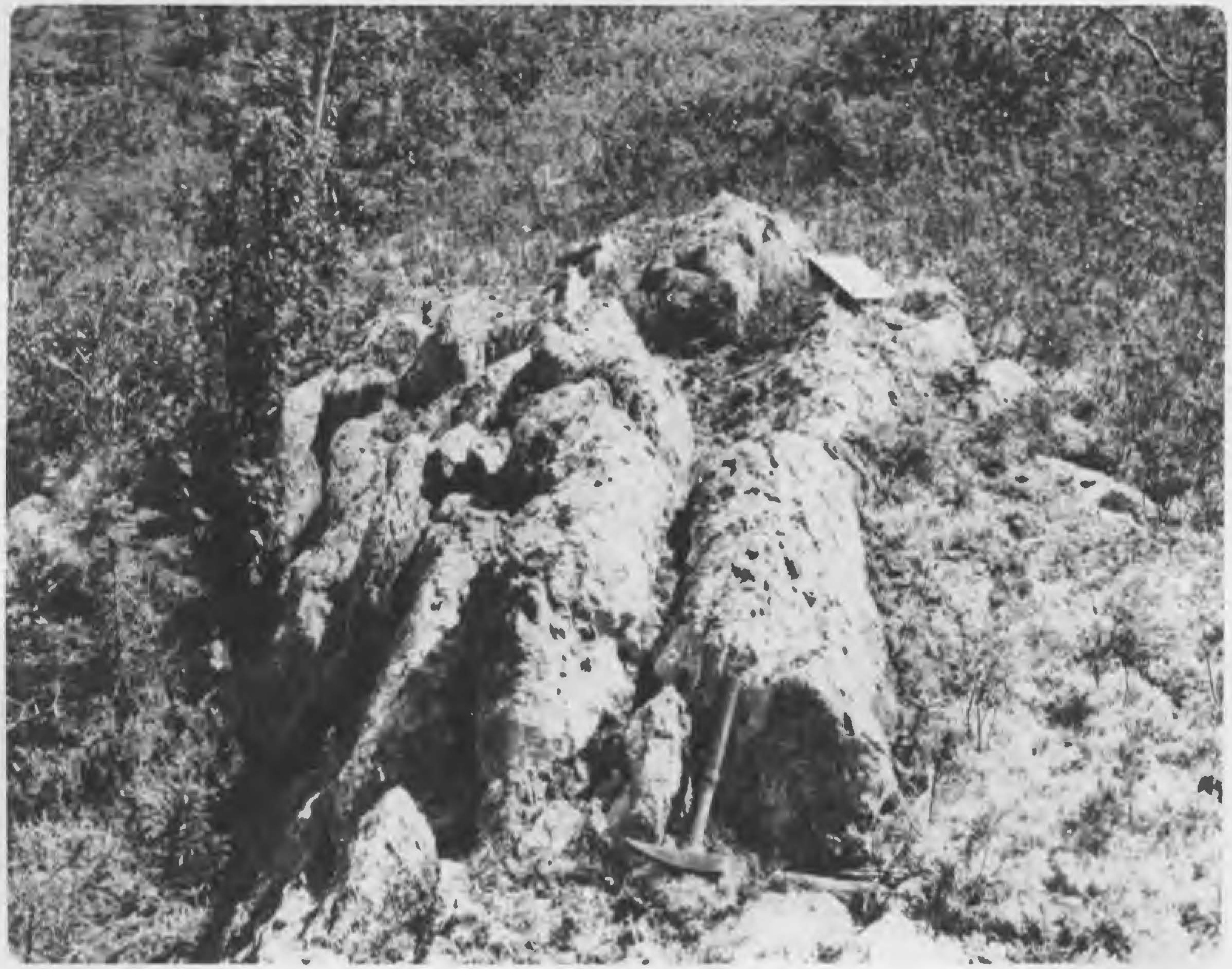
Surface installations of the Whalesback Mines, operated by British Newfoundland Exploration Limited. The mill, nearest foreground, and silos are located on the former Whalesback Pond bottom.

PLATE IV

PLATE IX



Compositional banding in massive St. Patrick Volcanics north of Little Deer Pond. Individual bands are about 5 inches thick.



Typical exposure of pillowed Whalesback Volcanics.
Pillows are elongated in the plane of schistosity,
roughly northeast.

PLATE V

PLATE VI

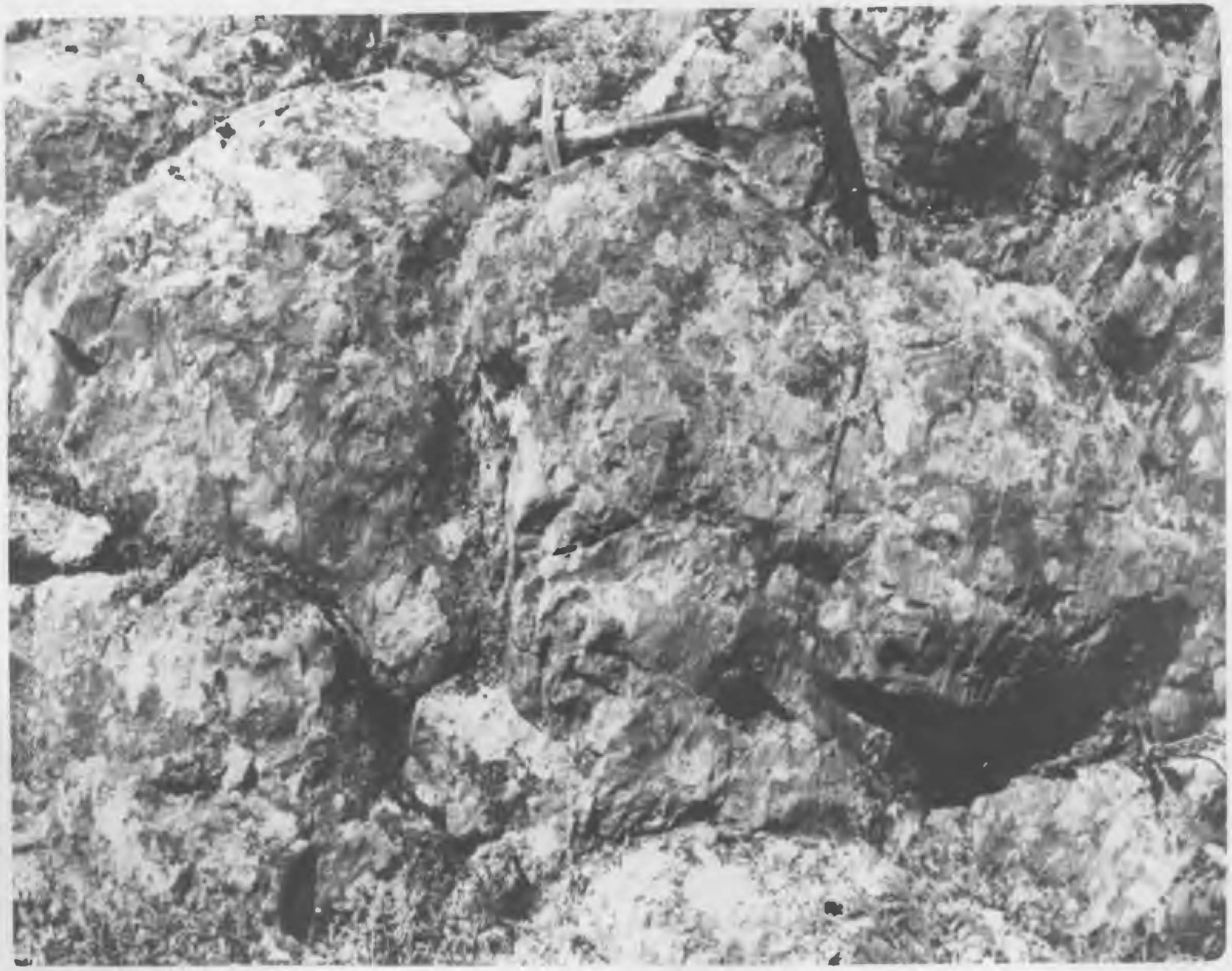
Outlines of highly deformed pillows in a glacially polished exposure of Whalesback Volcanics on the former Whalesback Pond bottom.

PLATE VII

Pillowed Whalesback Volcanics cut by 3 foot wide, felsite dyke. Plane of photography is about perpendicular to the northeasterly trending, vertical schistosity. Note elongation of pillows.

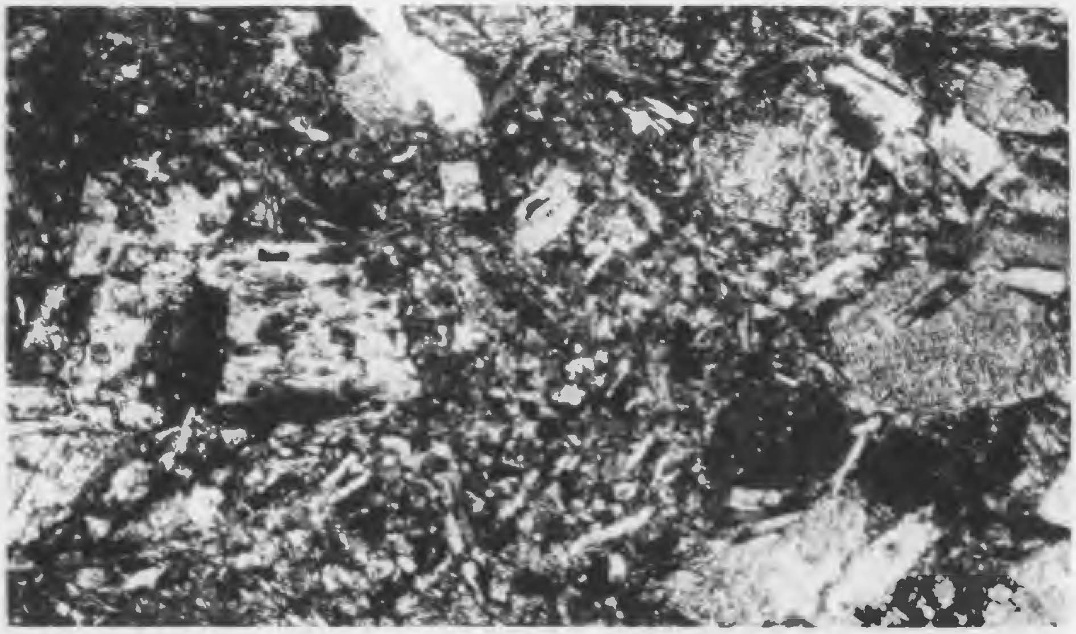
PLATE VIII

Pillowed St. Patrick volcanics in an exposure north of Little Deer Pond; view northeastward. Note the consistent size and undeformed character of the pillows in comparison to those of the Whalesback Volcanics.

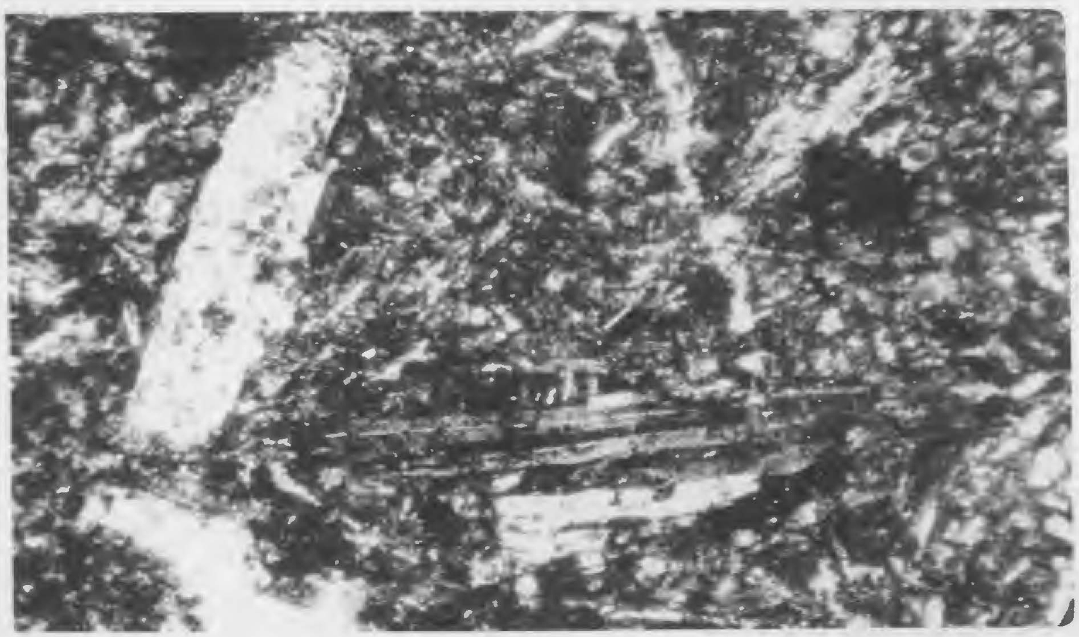


Pillows in St. Patrick Volcanics exposed about 20 feet north of the rocks shown in Plate IX. Plane of the photograph is approximately parallel to the plane of schistosity; tops up and facing northward.

PLATE X

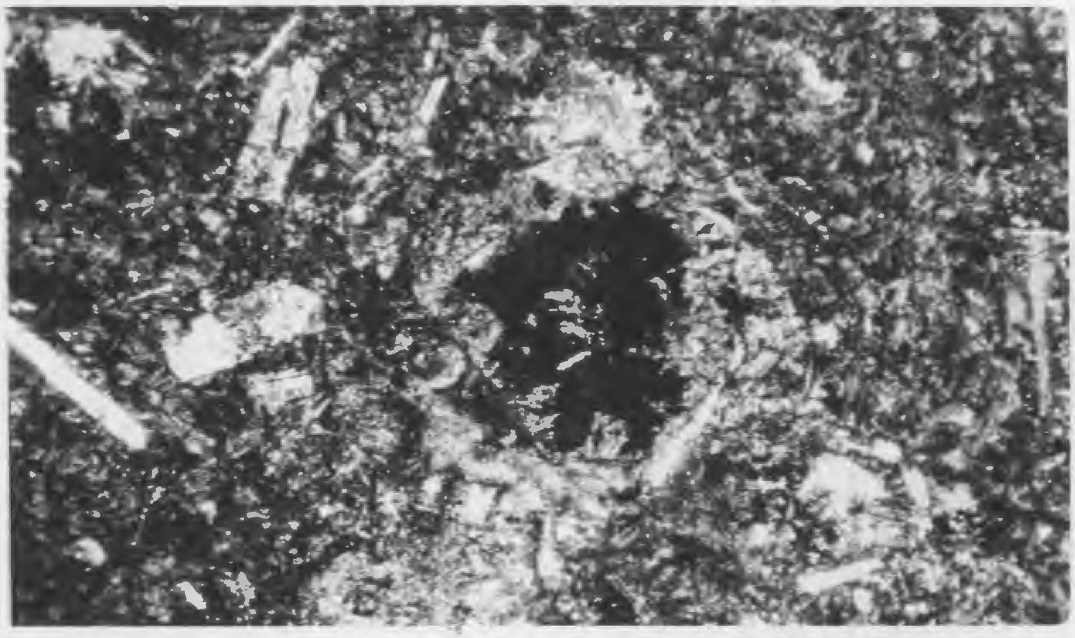


A. Photomicrograph illustrating the typical microporphyritic texture of the Whalesback Volcanics. Microphenocrysts of cloudy, indistinct albite at left and augite at right in a groundmass of epidote, albite, chlorite and amphibole, X-nicols. 30X.

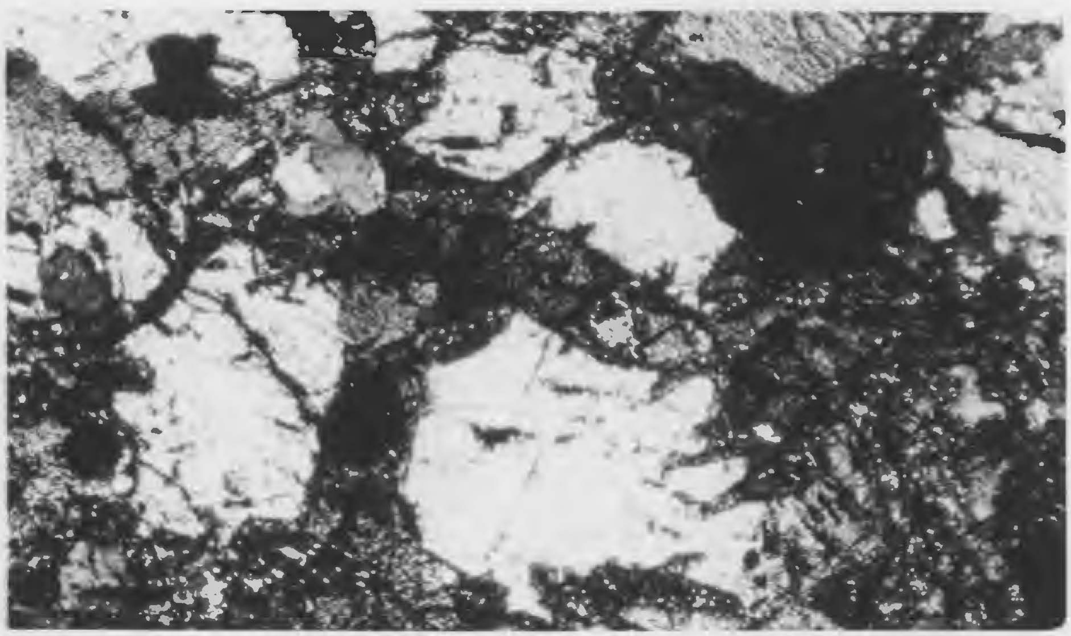


B. Photomicrograph - Albite microphenocrysts in Whalesback-type pillow lava. Note abundant inclusions and thin, tapering twin lamallae. X-nicols. 60X.

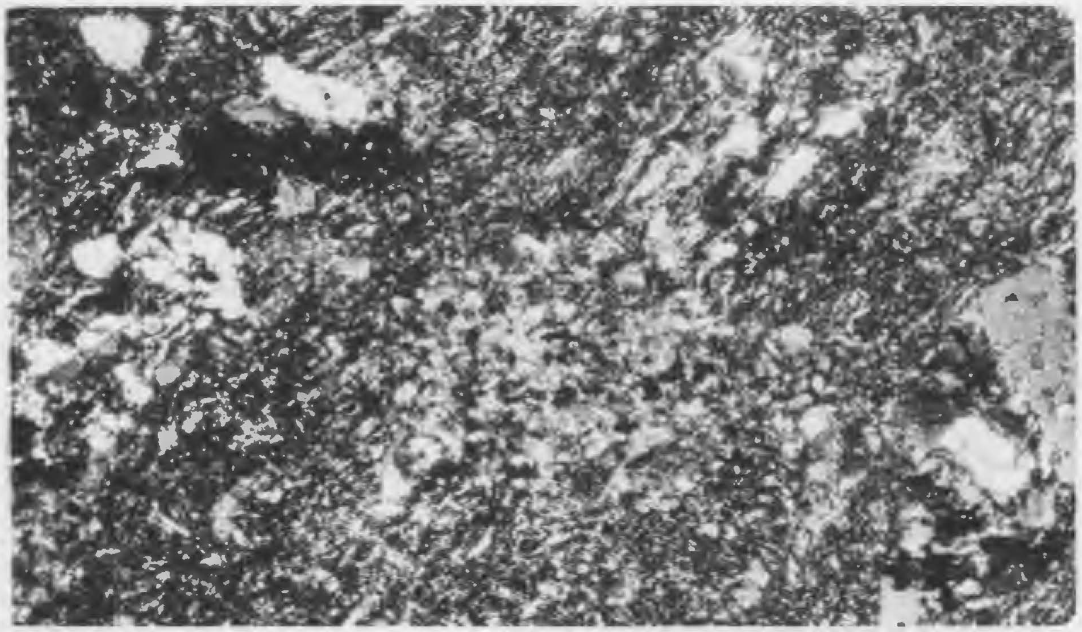
PLATE XII



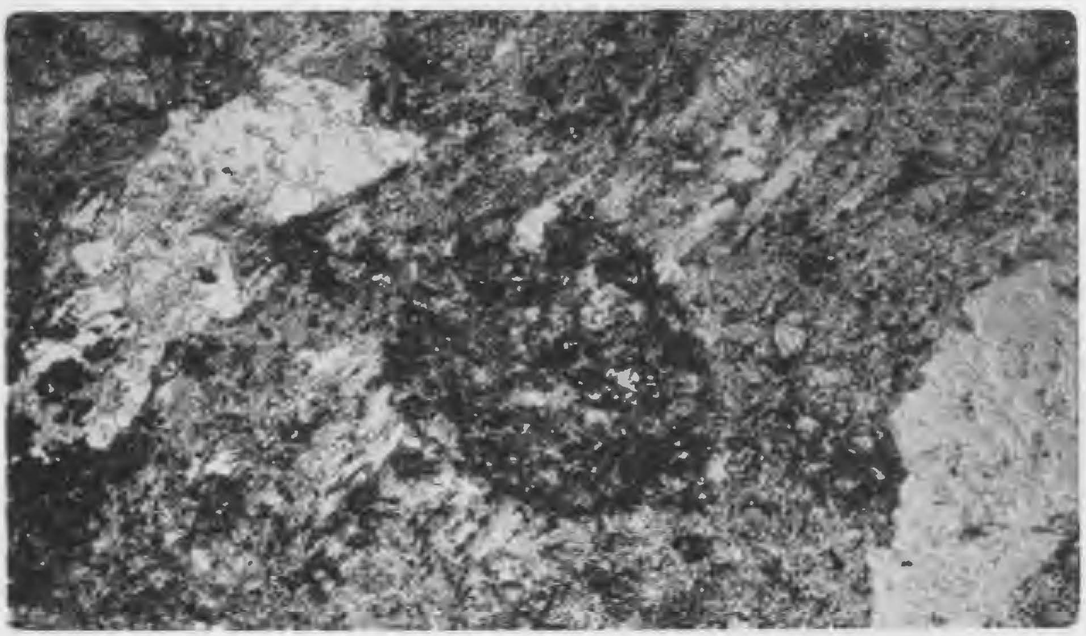
A. Photomicrograph - Augite (center of photo, at extinction) mantled by pale green, fibrous actinolite in Whalesback Volcanics. X-nicols. 30X.



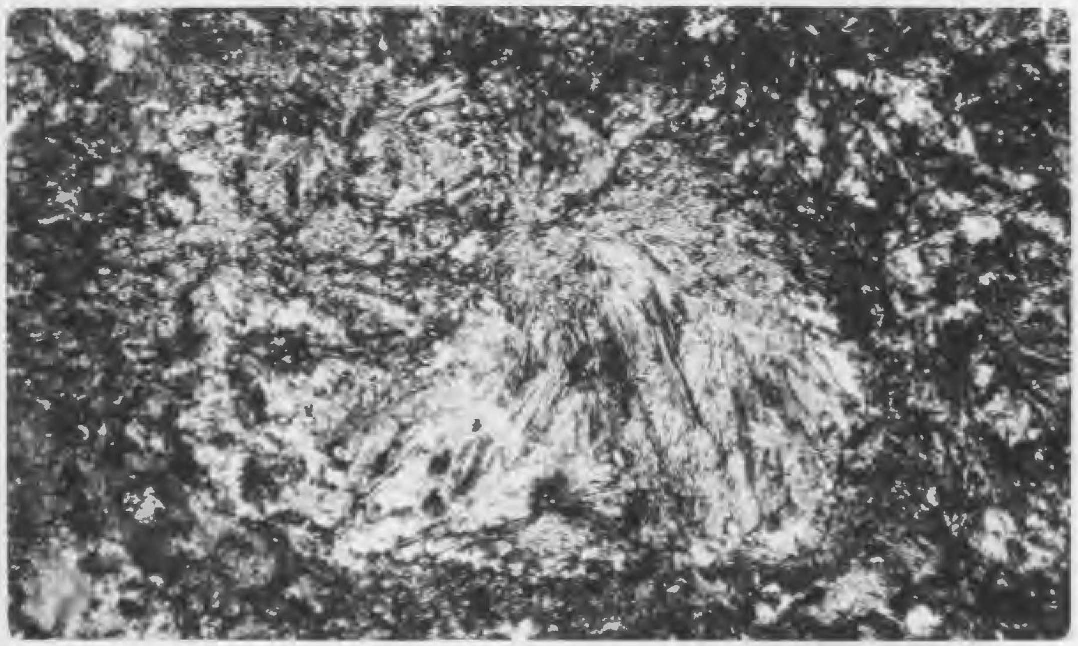
B. Photomicrograph - Augite microphenocrysts veined by chlorite. X-nicols. 60X.



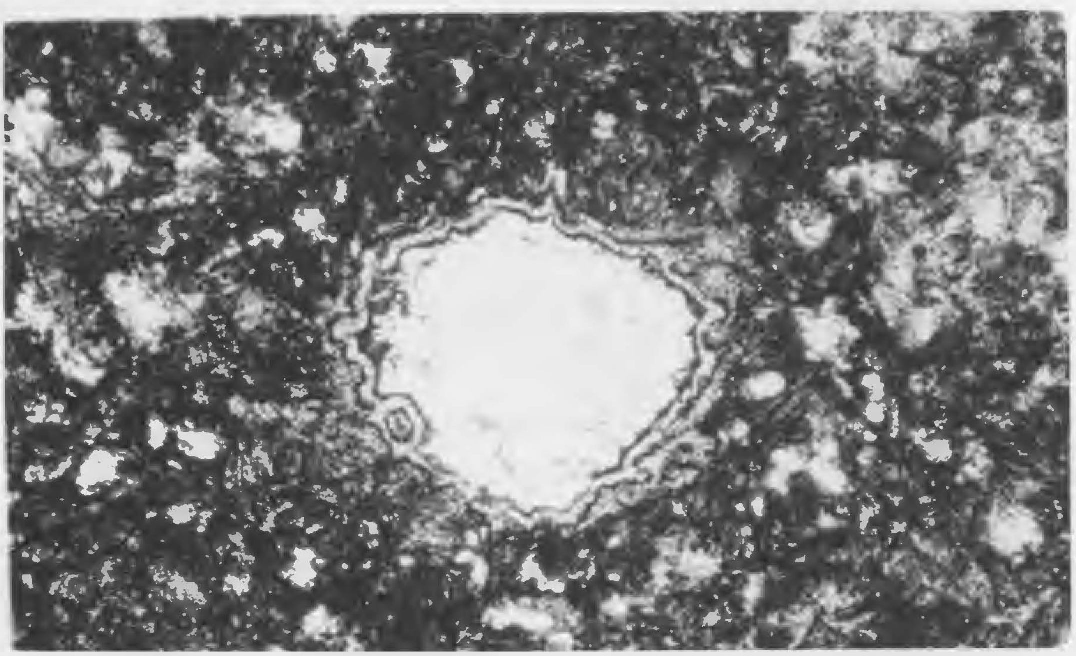
A. Photomicrograph - Cluster of granular epidote (center of photo) in Whalesback pillow lava. X-nicols. 30X.



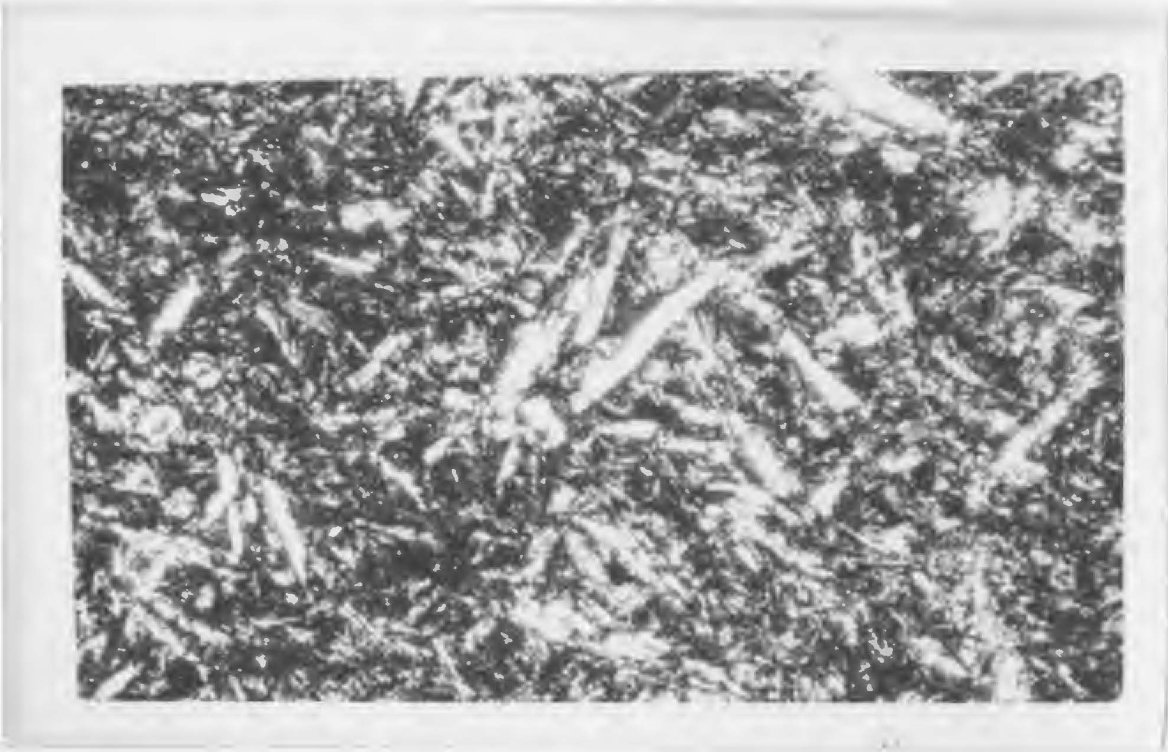
B. Photomicrograph - Same area as above under plane - polarized light. Note abundance of finely divided, opague leucoxene in epidote. 30X.



A. Photomicrograph - Sheaflike epidote in amygdule (?) lined by granular quartz in Whalesback-type metabasalt. X-nicols. 30X.



B. Photomicrograph - Amygdule of quartz, lined by epidote. Note segregation of leucoxene at epidote boundaries. Whalesback Volcanics. Plane-polarized light. 37.5X.

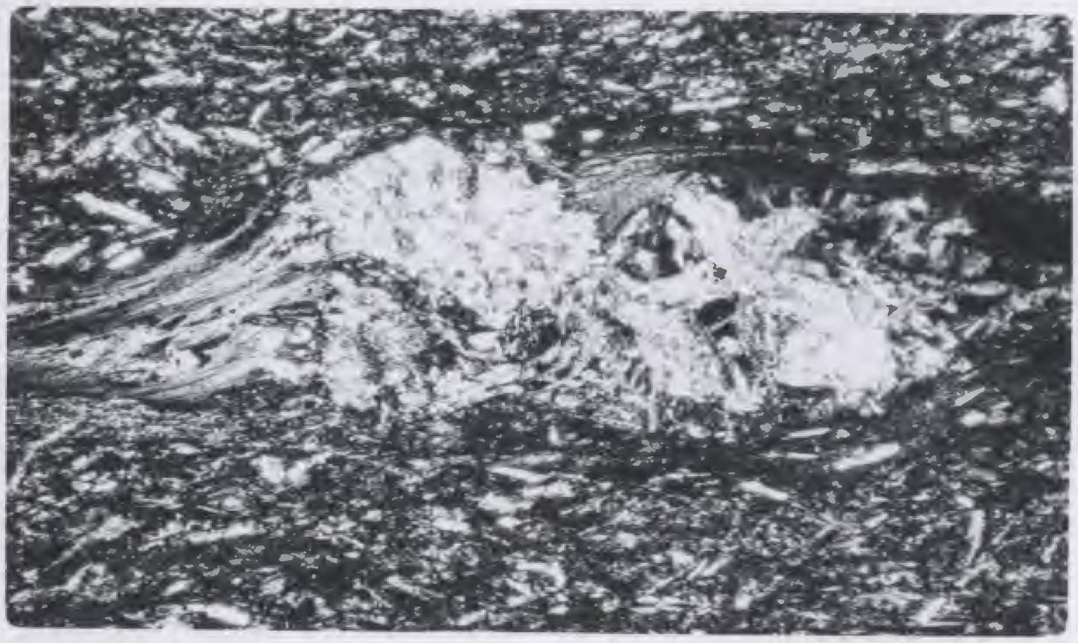


A. Photomicrograph illustrating texture typical of the St. Patrick-type pillow lava. Albite microlites in a groundmass of chlorite, amphibole and leucoxene. X-nicols. 60X.

B. Photomicrograph illustrating the typical texture of the massive variety of St. Patrick Volcanics, cloudy, broken and bent albite laths in a groundmass of chlorite, amphibole and leucoxene. X-nicols. 30X.

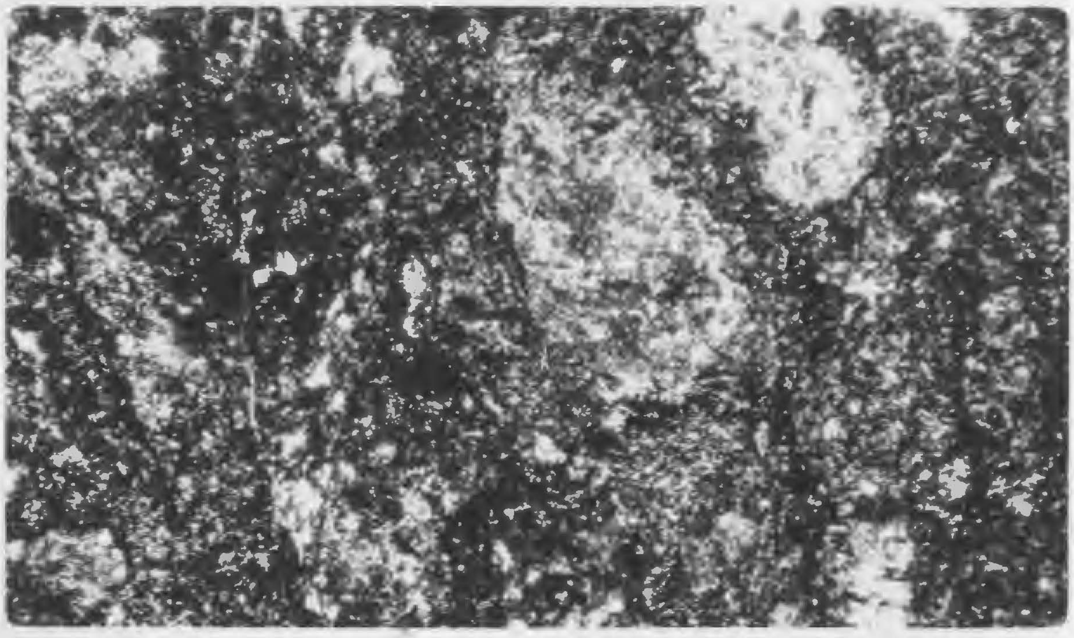
A. Photomicrograph - St. Patrick pillow lava with a well developed schistosity showing rough orientation of albite microlites. Dark area at upper left is chlorite, almost isotropic. X-nicols. 30X.

B. Photomicrograph - Granular epidote displaying lamellar twinning (upper center of photo). St. Patrick-type pillowed metabasalt. X-nicols. 189X.

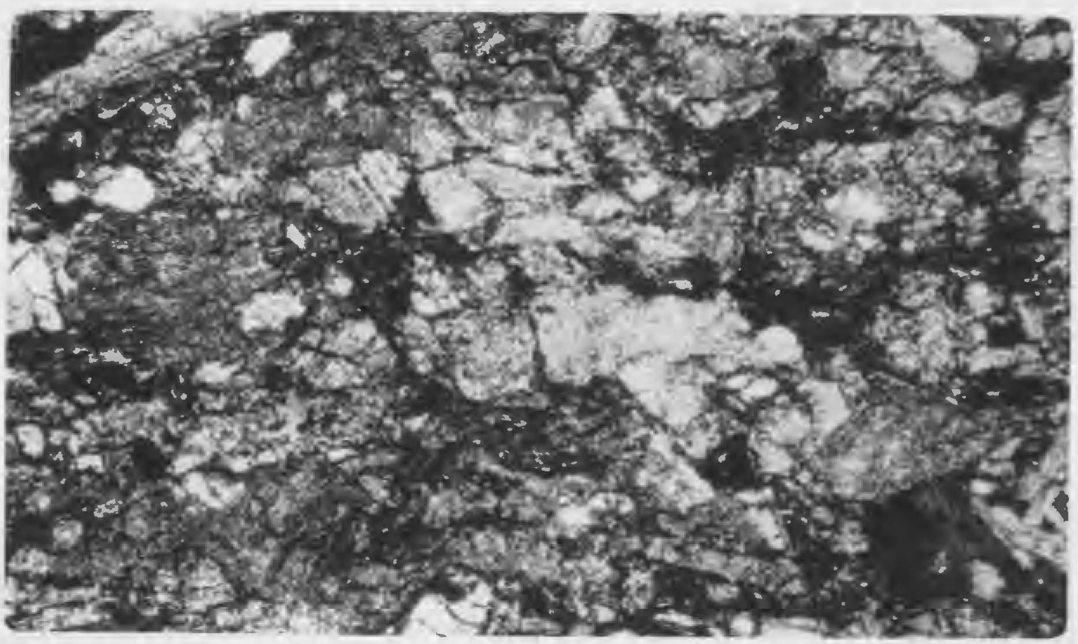


A. Photomicrograph - Distended veinlet of granular epidote, platey chlorite, and fibrous actinolite in St. Patrick-type metabasalt. X-nicols. 30X.

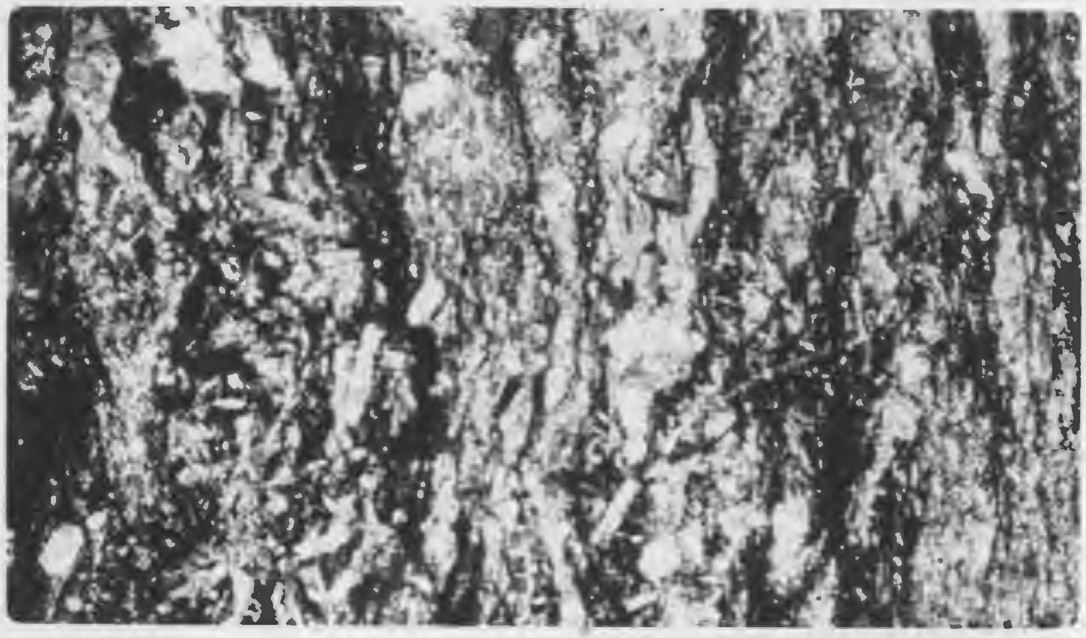
B. Photomicrograph - Amygdule of quartz and sheaflike epidote in St. Patrick-type metabasalt. Epidote is darkened by leucoxene inclusions. Note also the abundance of finely divided leucoxene in groundmass of rock. Plane-polarized light. 30X.



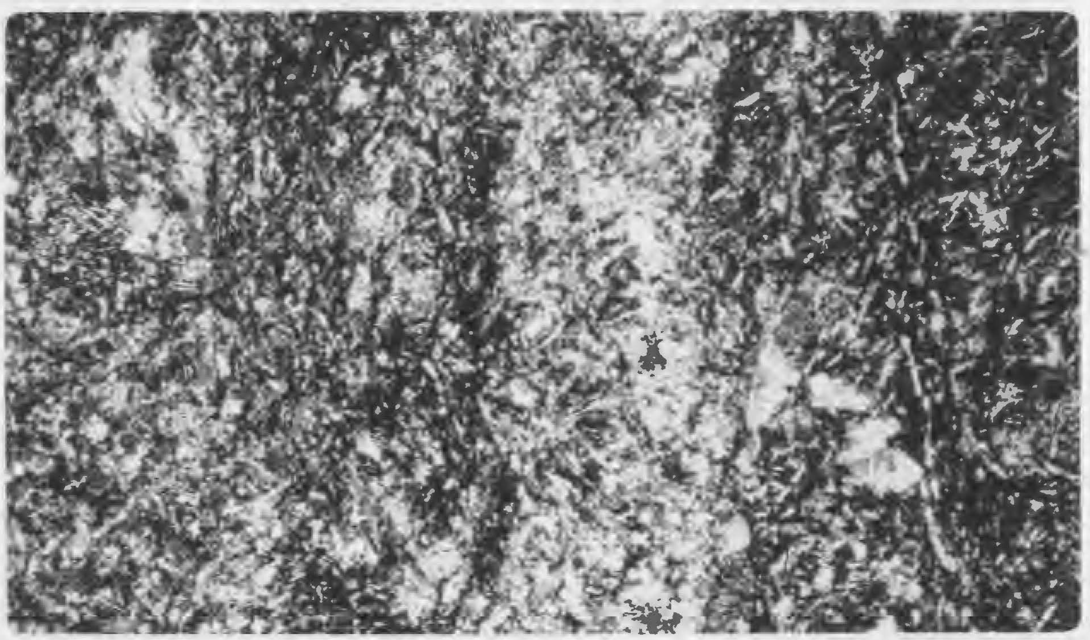
A. Photomicrograph - magnetic, schistose rock of probable pyroclastic origin. Mainly fine, granular quartz and plagioclase with some epidote and calcite and with abundant leucoxene and small magnetite grains. Light colored areas are mainly granular epidote. X-nicols. 30X.



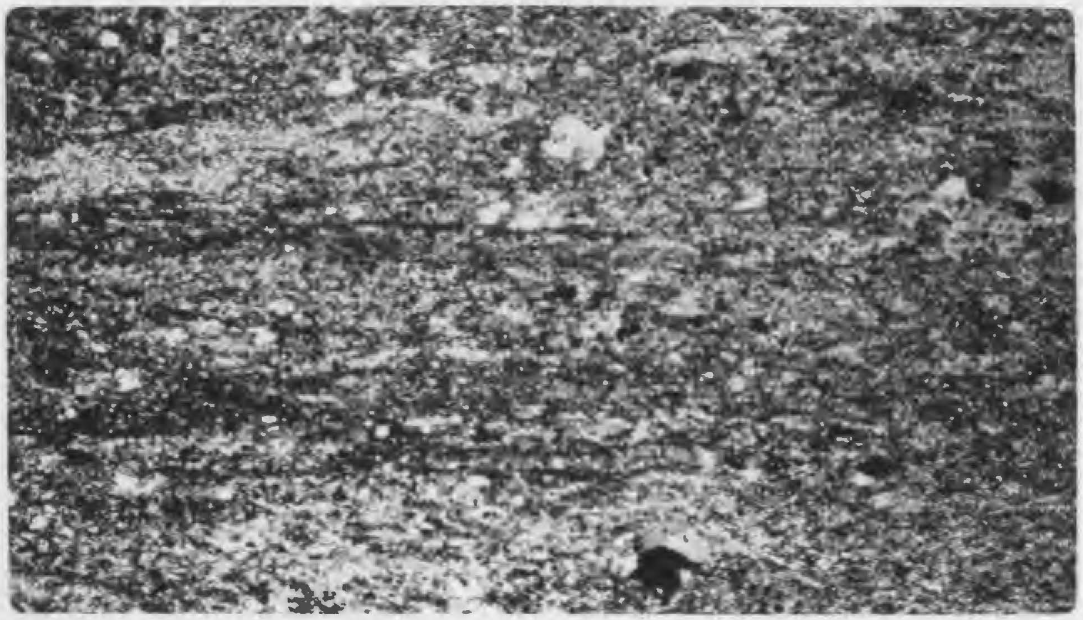
B. Photomicrograph - Variety of the magnetic schists consisting of sericitized plagioclase grains up to 1 mm. in length in a chloritic matrix with abundant leucoxene and fine magnetite. X-nicols. 30X.



A. Photomicrograph - Variety of the non-magnetic schists. Light-colored areas are quartz and albite with calcite and some sericite. Dark areas are mainly chlorite. X-nicols. 30X.

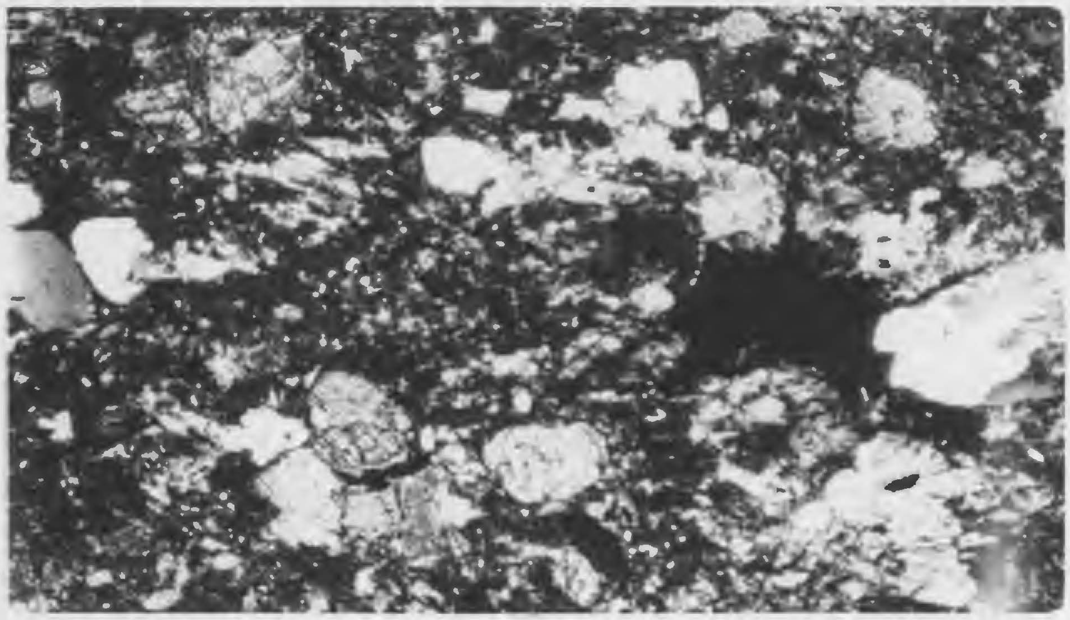


B. Photomicrograph - Plagioclase-rich schist of probable pyroclastic origin. Plagioclase microlites with quartz in a chloritic groundmass. X-nicols. 30X.



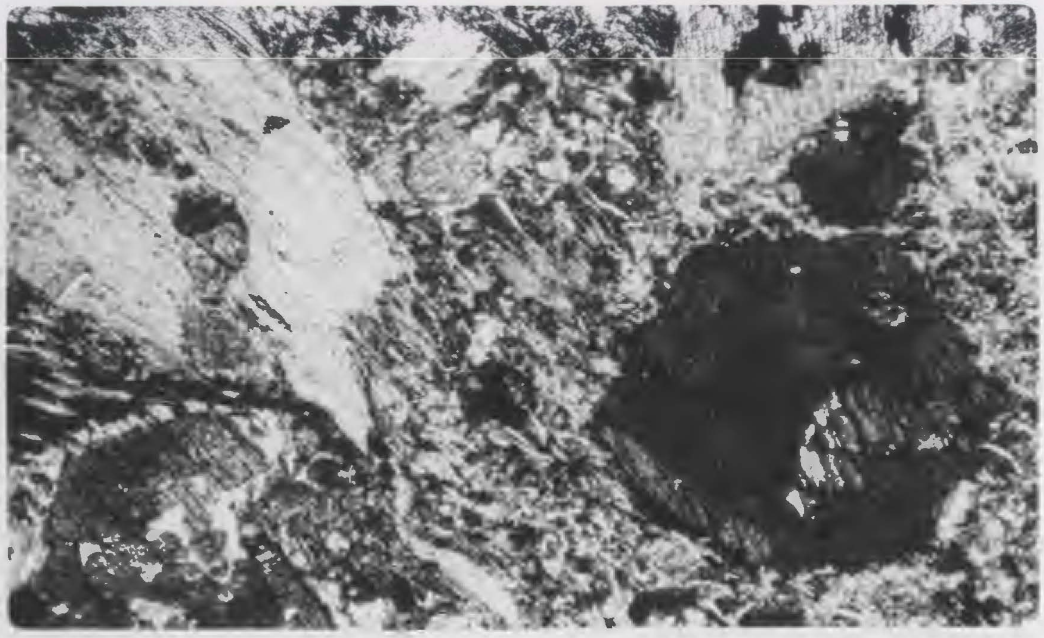
A. Photomicrograph - Chlorite-sericite schist. Mainly granular-quartz in a chloritic - sericitic matrix. X-nicols. 30X.

B. Photomicrograph - Matrix of agglomeratic rock. Finely granular quartz and chlorite in elongated aggregates outlined by finely divided leucoxene giving shard-like outlines - especially evident at center and left-bottom of photo. Larger grains are epidote. Plane-polarized light. 30X.

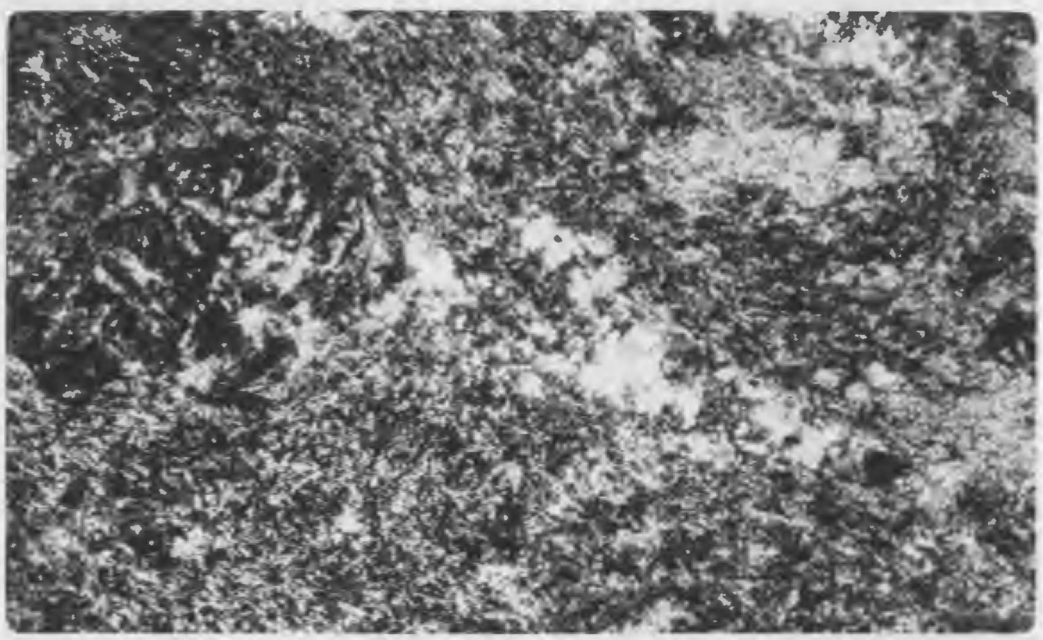


A. Photomicrograph - Gabbroic intrusive in the Whalesback pillow lavas. Cloudy plagioclase (bottom right) clinopyroxene (upper left) and epidote (lower center) in a chloritic groundmass with leucoxene. X-nicols. 30X.

B. Photomicrograph - Gabbroic intrusive in St. Patrick lavas. Cloudy plagioclase with granular leucoxene and magnetite in a chloritic and amphibolitic groundmass. X-nicols. 30X.



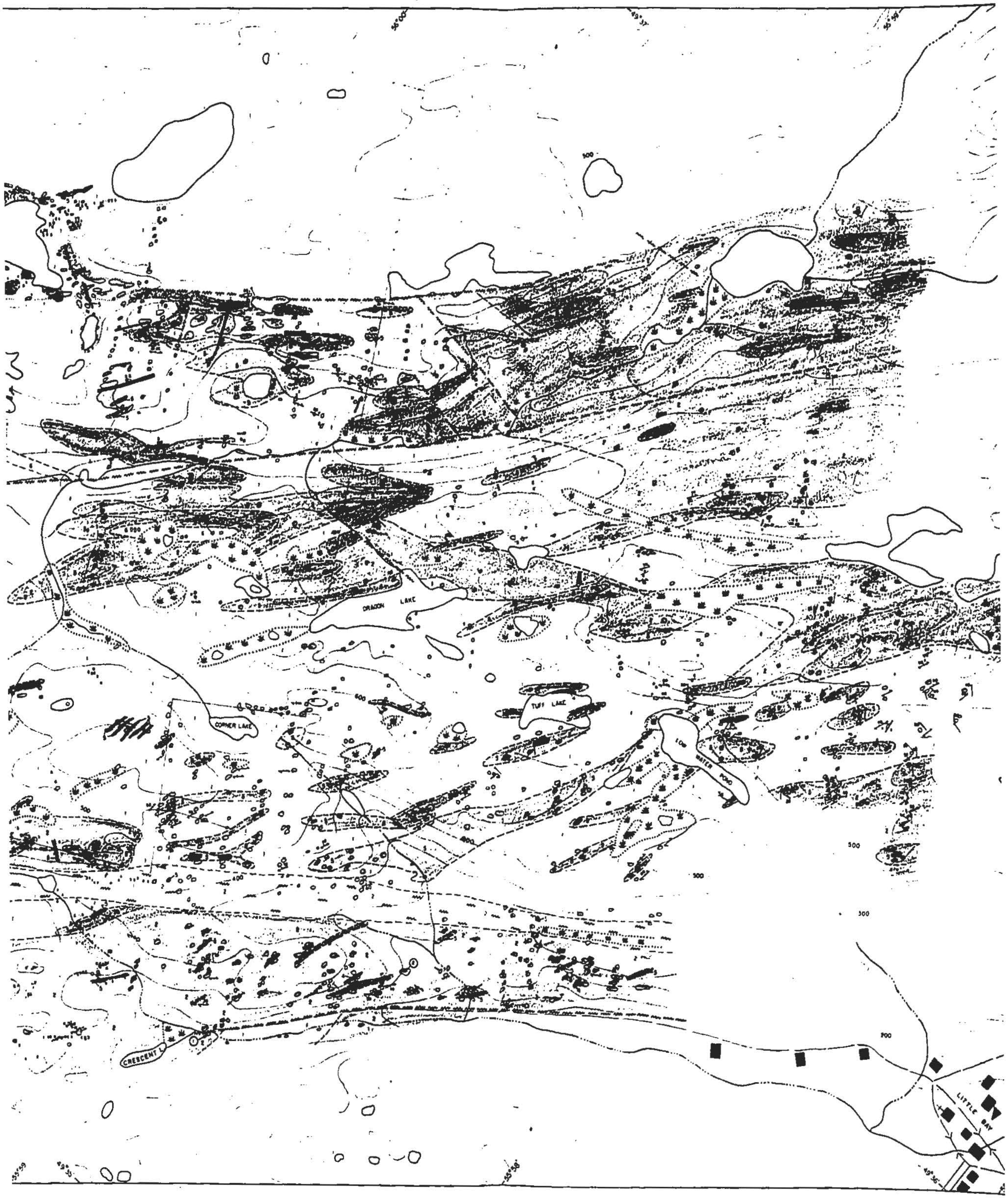
A. Photomicrograph - Pyroxene porphyry dyke. Phenocrysts of euhedral to subhedral, altered pyroxene in a groundmass of chlorite, amphibole and leucoxene. Mass at upper left is brownish chlorite. X-nicols. 30X.



B. Photomicrograph - Amphibole-feldspar porphyry dyke. Poorly outlined, highly chloritized amphibole (left center) and saussuritized feldspar (center right) in groundmass of plagioclase microlites with epidote, chlorite, amphibole and leucoxene. X-nicols. 30X.

1 of


BIG DEER POND
WHALESBACK POND
LITTLE DEER POND
BOUZANNE'S POND
SNAKE LAKE
N
400



DRAGON LAKE
TUFF LAKE
CORNER LAKE
LOW WATER POND
CRESCENT
LITTLE BAY

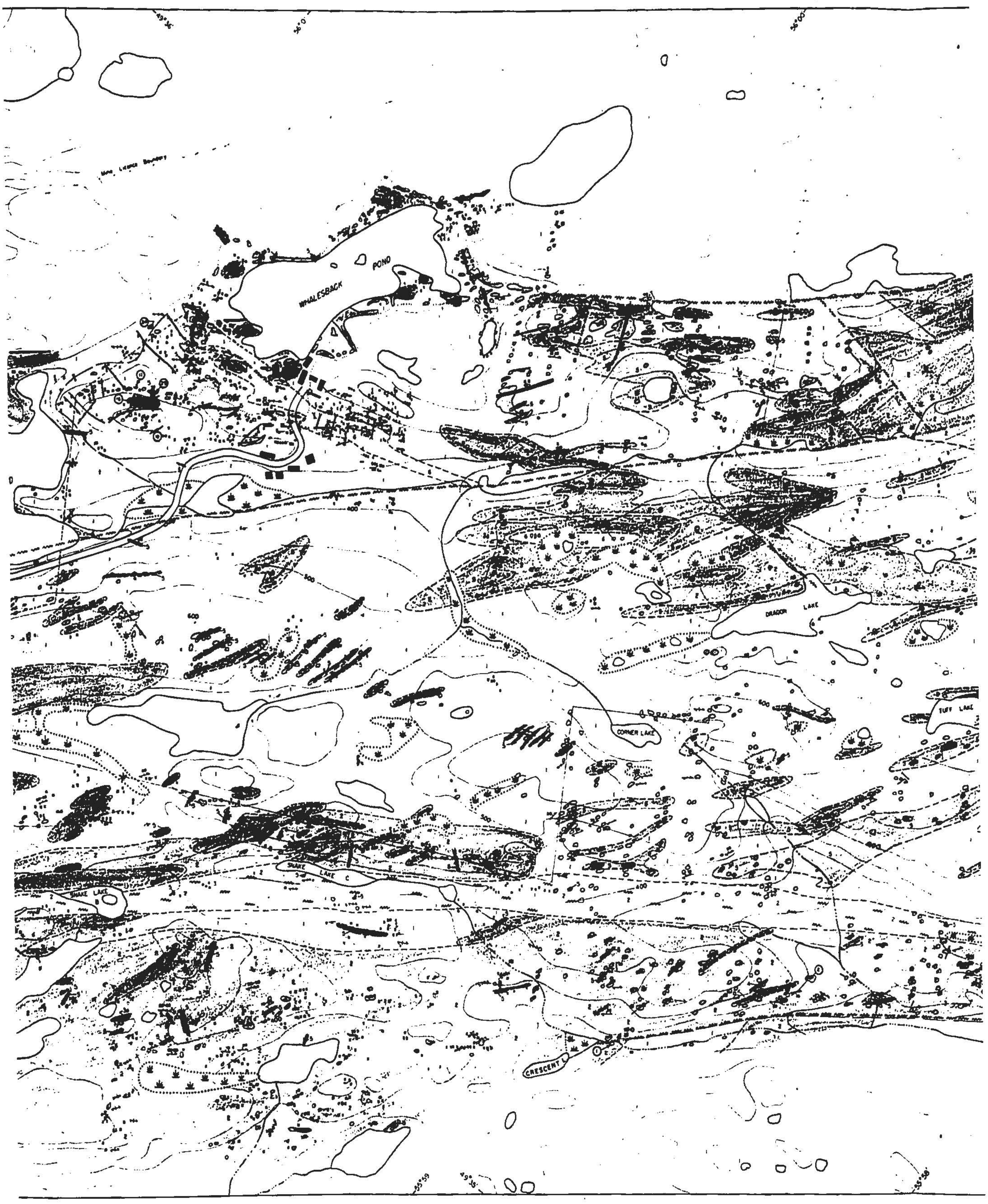

WHALESBACK POND
DRAGON LAKE
CORNER LAKE
TUFF LAKE
SNAKE LAKE
CRESCENT L

FIGURE 1.

GEOLOGY OF THE WHALESBACK AREA SPRINGDALE PENINSULA, NEWFOUNDLAND